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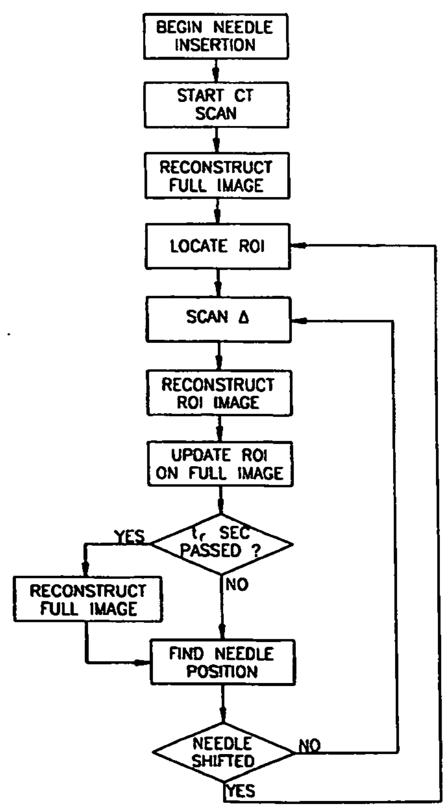
(54) Title: REAL-TIME DYNAMIC IMAGE RECONSTRUCTION

(57) Abstract

A method for modifying a planar image slice in a CT scanner having a predetermined reconstruction angle, comprising: reconstructing an image of the slice using initial X-ray attenuation data acquired along an initial scan path sector; acquiring additional X-ray attenuation data along an additional scan path sector in a vicinity of the axial position of the slice, the sector having an angular extent substantially less than the reconstruction angle; and modifying the image, to provide a modified image of the slice, responsible to the additional attenuation data.



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REAL-TIME DYNAMIC IMAGE RECONSTRUCTION

FIELD OF THE INVENTION

The present invention relates generally to computerized tomographic (CT) imaging, and specifically to CT imaging of dynamic physiological processes and interventional procedures.

BACKGROUND OF THE INVENTION

CT scanners are well known in the art. Generally, such scanners comprise an X-ray tube, mounted on an annular gantry, so as to revolve about a subject being imaged. The subject lies on a bed, which is translated through the gantry. The axis of translation of the bed (conventionally the Z-axis) is generally parallel to the long axis of the subject's body, which is typically perpendicular to the plane of revolution of the tube.

An array of X-ray detectors on the opposite side of the subject from the X-ray tube receive radiation transmitted through the subject. The detectors generate signals proportional to the attenuated X-ray flux incident thereon, corresponding to a series of circumferentially-disposed angular "views" through the subject. These signals are pre-processed to produce attenuation data, which are used in reconstructing a three-dimensional image of the subject. In "third-generation" scanners, the array of detectors is mounted on the gantry so as to revolve along with the X-ray tube, whereas in "fourth-generation" scanners, the detectors are arrayed in a ring, which is generally stationary.

CT scanners generally operate in axial or helical scan modes. In axial modes, the gantry and the bed move in alternation, i.e., the bed is held stationary at a given axial position while the gantry revolves about the subject. After a desired number of full or partial revolutions, the bed is advanced to the next, generally adjacent, axial position, and the gantry revolutions are repeated, thus continuing until all or a selected portion of the subject's body is scanned and corresponding image slices are reconstructed. In helical modes, the gantry revolves and the bed advances simultaneously, so that the X-ray tube describes a generally helical path relative to the body.

In a helical-mode scanner, in order to reconstruct a planar cross-sectional image slice of the subject at a desired axial position, based on the helical-scan views, effective attenuation values for each of a plurality of points around a circumference of such a planar slice are derived by interpolation between data received in the original helical-path views. For each of the plurality of points, the respective effective attenuation values correspond to the approximate attenuation along rays within the planar slice that pass through the point. For 360°

reconstruction, as is known in the art, the plurality of points are distributed around the entire circumference of the slice, whereas for 180° reconstruction, also known in the art, the points are distributed on a half-circumference. (For convenience in the following discussion, we will refer to the total angular extent of all the views that are collectively used in the reconstruction of a complete planar slice as the "reconstruction angle," typically 360° or 180°.) The interpolated data are filtered and back-projected to produce the cross-sectional image.

Cross-sectional images thus produced by CT scanners generally lag behind the acquisition of the attenuation data by several seconds at the least. This lag stems from several factors, including (1) the necessity of receiving data from views over the entire reconstruction angle (or more, in the case of helical scanners) before reconstructing the image; and (2) the time needed to complete the intensive computations involved in back-projecting an entire image slice. The lag is particularly disadvantageous when CT imaging is used to track the progress of a physiological process, such as the flow of a contrast material. Similarly, when the CT scanner is used to guide a surgical procedure, such as a biopsy, the surgeon receives visual feedback regarding his progress in the procedure with a delay of more than one scan period.

Multi-slice axial and helical-path scanners are known in the art. For example, U.S. patent 5,485,493, which is incorporated herein by reference, describes a multiple-detector-ring spiral scanner with relatively adjustable helical paths, in which two adjacent, parallel slices are acquired along two parallel paths simultaneously or sequentially. Data corresponding to planar slices are derived by interpolating between data acquired along the two helical paths.

U.S. Patent 5,524,130, the disclosure of which is incorporated herein by reference describes a number of methods for utilizing a single detector ring scanner to provide successive axially spaced slices with reduced time between reconstruction of the slices. Some of these methods appear to utilize partial scan data from one scan to replace data from a second scan for reducing the reconstruction time.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for rapid image reconstruction based on axial or helical-scan CT data.

In one aspect of the present invention, the CT data comprise multiple-slice CT data, acquired using a multi-row detector array.

In another aspect of the present invention, helical-scan data are used to reconstruct planar corrected image slices, which are displayed sequentially as the scan proceeds.

It is a further object of the present invention to provide a method for near-real-time CT imaging of physiological processes and interventional treatments.

In preferred embodiments of the present invention, a CT scanner comprises an X-ray tube, mounted to revolve on an annular gantry about a bed on which a subject lies, and a detector array. The bed is advanced through the gantry along a translation axis that is generally parallel to the long axis of the subject's body. The X-ray tube thus irradiates the subject from multiple positions, or "views," along this trajectory. The detector array comprises at least one and preferably two or more parallel rows of X-ray detector elements in a multi-row detector array, each row having a long axis disposed in a generally circumferential direction with respect to the long axis of the subject's body.

The detector elements receive radiation that has passed through the subject's body at each of the views and generate signals responsive to attenuation of the X-rays. These signals are preprocessed, as is known in the art, to generate effective attenuation values, which are associated with planar slices through the body that are generally perpendicular to the translation axis. Optionally, the attenuation values are re-binned, as is known in the art, to arrange the values in a format corresponding to an array of parallel beams through the body. The attenuation values are filtered and back-projected to calculated CT values, which are used to reconstruct cross-sectional CT images and then to update the images substantially in real time.

In some preferred embodiments of the present invention, the CT scanner is a multiple slice helical-path scanner as described in an Israel patent application entitled "On-Line Image Reconstruction in Helical CT Scanners," filed on February 20, 1997 and assigned application number 120277 and a PCT application having the same title filed on even date with the present application, whose disclosures are incorporated herein by reference. In these embodiments, effective attenuation values are calculated for each of a plurality of points on a periphery of each planar slice by weighted interpolation between first and second measured attenuation values, taken from respective first and second line images within a single view. The first and second line images are derived respectively from data received simultaneously from first and second rows of detector elements. Thus, a complete cross-sectional CT image is reconstructed within a time window corresponding to a single, initial revolutionary scan of the tube over the reconstruction angle, typically 180° or 360°.

In preferred embodiments of the present invention, an initial planar image slice is reconstructed at a selected axial position as described above, using data from a 360° (or 180°)

scan in a vicinity of the position, along either an axial or a helical scan path. The initial image is then updated and modified continually by incorporation of additional attenuation data acquired from angular views further along the scan path, as the tube continues to revolve.

Preferably, the planar image is displayed, for example on a CRT display screen, as is known in the art, and the display is updated continually as the image is updated. Additionally or alternatively, as the image is updated, it is recorded in digital or analog format for subsequent playback.

Further preferably, the additional data are processed so as to back-project effective attenuation values derived from the additional data and thus to produce an image data matrix. This matrix is added to the planar slice image, while a similar matrix, back-projected from values derived from the data acquired from the preceding scan, is subtracted.

Alternatively, processing the additional data may include adding the additional data and subtracting corresponding data acquired in the preceding scan, or taking the difference of respective effective attenuation values derived from the additional and the preceding data. The resultant difference is back-projected to produce an image data matrix, which is added to the planar slice image.

In some preferred embodiments of the present invention, a region of interest (ROI) is designated within a selected planar image slice, and the image in this ROI is updated, using methods described above, at a higher update rate than the remainder of the slice image. Limiting the image updating operation to the ROI allows the ROI image to be reconstructed more rapidly than the entire slice could be updated. When changes take place within the ROI, they are thus displayed in the reconstructed image with a shorter time lag than could be achieved if the entire slice were updated.

Preferably, the full planar image slice is reconstructed intermittently, and the ROI image is registered with the full slice image.

In some preferred embodiments of this type, the ROI is selected to include an object of interest, for example, a biopsy needle. The position of the object in the image is tracked, preferably using means and methods of automated image analysis known in the art, and the boundaries of the ROI are varied as appropriate to keep the object within the ROI.

In some preferred embodiments of the invention, this tracking of position takes place within a slice, in other preferred embodiments of the invention, where multiple slices are reconstructed and optionally displayed, tracking takes place intra-slice and slices are presented

and/or reconstructed such that the slice which contains the needle tip is in or near the center of the group of slices which are reconstructed. Where only a single slice is displayed, the displayed slice is changed such that the slice which contains the needle tip is presented. Optionally, a new slice is reconstructed in which the needle tip is substantially axially centered.

It will be appreciated that the principles of the present invention are equally applicable to third- and fourth-generation CT scanners, and to various image reconstruction methods, including 180°, 360°, fan beam and parallel beam reconstruction, as are known in the art. Furthermore, although some preferred embodiments of the present invention are described with reference to multi-slice, helical-path scanners, the principles of the present invention are similarly applicable to both single-slice and multi-slice axial-scan CT systems.

Moreover, although in the preferred embodiments described herein, the Z-axis, along which the bed advances, is generally perpendicular to the plane of revolution of the tube, the principles of the present invention may similarly be applied to CT image reconstruction using angled helical scan paths, as described in a PCT patent application PCT/IL97/00069, filed on February 20, 1997, entitled "Helical Scanner with Variably Oriented Scan Axis," which is assigned to the assignee of the present invention, and whose disclosure is incorporated herein by reference. This application designates the US.

There is therefore provided, in accordance with a preferred embodiment of the present invention, a method for modifying a planar image slice in a CT scanner having a predetermined reconstruction angle, comprising:

reconstructing an image of the slice using initial X-ray attenuation data acquired along an initial scan path sector;

acquiring additional X-ray attenuation data along an additional scan path sector in a vicinity of the axial position of the slice, the sector having an angular extent substantially less than the reconstruction angle; and

modifying the image, to provide a modified image of the slice, responsive to the additional attenuation data.

Preferably the method includes defining a region of interest within the image slice, wherein modifying the image comprises modifying only a portion of the image corresponding to the region of interest. Preferably, defining the region of interest comprises identifying an object of interest and altering the region of interest in response to movement of the object. Preferably, altering the region of interest in response to movement of the object comprises

determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest in response to a change is the characteristic. Preferably, determining the characteristic of the X-ray attenuation data comprises finding a maximum value of the data within a data window corresponding to the region of interest. Preferably, finding the maximum value of the data comprises pre-processing the data and finding a maximum value of the pre-processed data.

In a preferred embodiment of the invention, acquiring the data along the initial and additional scan path sectors comprises acquiring multi-slice data along the sectors of the scan path. Preferably, acquiring data along the sectors of the scan path comprises acquiring the data along sectors of a helical scan path. Alternatively, acquiring the data along the scan path sectors comprises acquiring the data along sectors of a generally circular scan path substantially within a plane at the axial position of the slice.

In a preferred embodiment of the invention, modifying the image responsive to the additional attenuation data comprises processing the additional attenuation data and the initial attenuation data to produce an image data matrix and adding the matrix to the image.

Preferably processing the attenuation data to produce the image data matrix comprises:

back-projecting attenuation values calculated from the additional data, to determine a first preliminary matrix;

back-projecting attenuation values calculated from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector, to determine a second preliminary matrix; and

subtracting the second preliminary matrix from the first preliminary matrix to produce the image data matrix.

Alternatively, processing the attenuation data to produce the image data matrix comprises:

calculating initial attenuation values from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector;

calculating additional attenuation values from the additional data;

subtracting the initial attenuation values from the additional attenuation values to determine difference values; and

back-projecting the difference data to produce the image data matrix.

There is further provided, in accordance with a preferred embodiment of the invention, a method for producing a CT image of a region of interest within the body of a subject, comprising:

reconstructing a CT image of a slice of the body;

defining the region of interest; and

updating the CT image only in the region of interest, wherein the image of the region of interest encompasses only a portion of the CT image of the slice.

Preferably, the method comprises superimposing the CT image of the region of interest on another CT image encompassing a substantially greater portion of the cross-sectional area. Preferably, the updated image of the region of interest is produced utilizing one of the above defined methods.

In a preferred embodiment of the invention, the region of interest is determined based on an expectation of change in the CT image in the region of image.

Additionally or alternatively, the method includes identifying an object of interest and wherein defining the region of interest comprises defining the region of interest in response to a determination of the position of the object of interest. Preferably, the method comprises altering the region of interest being reconstructed in response to movement of the object.

In a preferred embodiment of the invention, altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest being reconstructed in response to a change in the characteristic. Preferably, determining the characteristic of the X-ray attenuation data comprises finding an extremum value of the data within a data window corresponding to the region of interest. Preferably, finding the extremum value of the data comprises preprocessing the data and finding a maximum value of the pre-processed data.

In a preferred embodiment of the invention, the CT image is a multi-slice image and wherein the position of the slices are determined based on a determination of the position of the object with respect to the slices.

There is further provided, in accordance with a preferred embodiment of the invention, a method of determining an optimal position for multiple CT slices, comprising:

reconstructing the multiple slices based on a first set of data;

determining the position of an object in the slices;

then reconstructing the slices based on the determined position.

In a preferred embodiment of the invention, the object is a biopsy needle.

There is further provided, in accordance with a preferred embodiment of the invention, an imaging method for the determination of the position of a biopsy needle comprising:

reconstructing a CT image from a plurality of views;

determining the position of the biopsy needle in the image; and

determining a region of interest based on the determined position of the biopsy needle.

In a preferred embodiment of the invention, the method includes periodically updating the image only in the region of interest.

There is further provided, in accordance with a preferred embodiment of the invention, an imaging method for imaging a region in a region of interest in which changes are expected comprising:

reconstructing a CT image from a plurality of views; and

periodically modifying the image only in the region of interest.

In a preferred embodiment of the invention, the image is periodically modified utilizing one of the above defined methods.

The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of a CT scanner, operative in accordance with a preferred embodiment of the present invention;

Fig. 2 is a graph that schematically illustrates an aspect of the operation of the scanner of Fig. 1, in accordance with a preferred embodiment of the present invention;

Fig. 3 is a schematic illustration of a CT image showing an interventional procedure performed on the body of a subject, in accordance with a preferred embodiment of the present invention;

Fig. 4 is a flow chart schematically illustrating a method used in performing the procedure of Fig. 3, in accordance with a preferred embodiment of the present invention; and

Fig. 5A and 5B are schematic illustrations of a CT imaging of an interventional procedure performed on the body of a subject, in accordance with a preferred embodiment of the present invention utilizing a multi-slice system.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to Fig. 1, which shows a CT scanner 20, operative in accordance with a preferred embodiment of the present invention. Scanner 20 comprises a bed 24, supported by a base 26, on which bed a subject 22 lies while his body is being imaged by the scanner. Scanner 20 further comprises an X-ray tube 28, which irradiates subject 22, and a detector array 30, which receives X-rays from tube 28 and generates signals responsive to the attenuation of the X-rays in passing through the subject's body. Preferably, array 30 comprises multiple, parallel rows of X-ray detector elements 23. Alternatively, array 30 may comprise only a single row of detector elements.

Tube 28 and array 30 are mounted on an annular gantry 32, so as to revolve about subject 22. Bed 24 is advanced through gantry 32 along an axis 34, taken to be the Z-axis of a scanning coordinate system. Z-axis 34 is generally parallel to the long axis of the subject's body. Scanner 20 preferably operates in an axial mode, wherein bed 24 is held stationary while tube 28 and array 30 revolve there about. However, in some aspects of the invention, scanner 20 may alternatively operate in a helical mode, wherein tube 28 and array 30 revolve simultaneously with the advance of bed 24 through gantry 32.

Scanner 20 as pictured in Fig. 1 is of a type known in the art as a third-generation CT-scanner, characterized in that both tube 28 and detector array 30 revolve about subject 22. It will be appreciated, however, that the principles of the present invention and the methods of image reconstruction to be described below are equally applicable to other types of CT scanners, in particular fourth-generation CT scanners, in which the detectors form a substantially stationary ring around subject 22.

At each of a plurality of selected locations of tube 28 along its scan path, data acquisition circuitry 36 acquires a "view," i.e., the circuitry receives signals from each element 23 of array 30 responsive to X-ray attenuation along a ray from tube 28 to the element. Each such view comprises one or more parallel line images, each line image corresponding to one of the one or more rows of array 30.

For each view, data acquisition circuitry 36 performs signal normalization and logarithm operations, as are known in the art, to derive X-ray attenuation data corresponding to each of elements 23. Image reconstruction circuitry 40 receives these data and derives effective attenuation values at a plurality of points on a periphery of a planar image slice, at a selected position along Z-axis 34. These effective values are filtered and back-projected, using methods

known in the art, to produce a planar image slice at the selected position. A plurality of these planar image slices are typically produced, so as to reconstruct a three-dimensional CT image set of the body of subject 22. Preferably, these image slices are stored in image memory 42 and displayed by display unit 44, and they may be otherwise printed and/or processed as is known in the art.

In some preferred embodiments of the present invention, in which CT scanner 20 operates in an axial scan mode, an image slice is reconstructed at a given axial position of bed 24 after views have been acquired over an angular scan extent that is generally equal to the reconstruction angle, for example, 180°, at the axial position, as is known in the art. Thereafter, tube 28 continues to revolve about subject 22 at this position, and this original image is modified and updated, as will be described below, by incorporating attenuation data acquired in additional angular views, for as long as bed 24 remains at this axial position.

In other preferred embodiments of the present invention, in which scanner 20 operates in a helical scan mode, an image slice at a given axial position is similarly reconstructed, as described in a PCT patent application entitled "On-line Image Reconstruction in Helical CT Scanners," filed on even date, which is referenced above and which is incorporated herein by reference. The initial image is first reconstructed using views acquired over a portion of the helical scan path having an angular extent generally equal to the reconstruction angle, for example, 180°, in a vicinity of the axial position. Thereafter, this initial image is modified and updated, as will be described below, by incorporating attenuation data acquired at additional view angles along the helical path. This modification and updating can continue for as long as tube 28 and array 30 dwell close enough to the axial position of the slice so that the slice remains within the detection area of at least one of the rows of the array. Preferably, the helical scan path has a pitch that is substantially less than the width of array 30, so that the dwell time of tube 28 and array 30 at a given position is equal to at least the period of one complete revolution about subject 22.

Fig. 2 is a graph that schematically illustrates ranges of view angles θ over which attenuation data are acquired, as a function of time, for the purpose of reconstructing and updating a planar slice image at a given axial position Z, in accordance with preferred embodiments of the present invention. Initially, views of subject 22 are acquired as tube 28 scans through a 180° angular range from θ_0 to $\theta_0+180°$, finishing at a time T_1. This range is divided into six 30° sectors, labeled 50, 52, 54, 56, 58 and 60 in Fig. 2. Generally, each of the

sectors includes a plurality of views. The attenuation data acquired in each of these sectors are interpolated and back-projected to produce a partial data matrix, and the six data matrices thus produced are combined to reconstruct the planar slice image, using 180° reconstruction.

The tube is then scanned through the next 30° sector, labeled 62, and attenuation data are acquired from the same views as in sector 50 (although now seen from the opposite side of the body of subject 22). The data acquired in sector 62 are interpolated, filtered and back-projected, as described above, to produce a new partial data matrix, which is added into the planar slice image, and the matrix corresponding to sector 50 is subtracted out. In this way, changes in the body of subject 22 occurring in the area of the slice may be observed in the image. Alternatively, the partial data matrix corresponding to sector 62 may be averaged in with the matrix corresponding to sector 50, so as to smoothly alter and improve the quality of the image.

As the scan proceeds through the next 30°, a partial data matrix is produced corresponding to the next sector, labeled 64, replacing the matrix of sector 52, and so forth. The planar slice image is thus updated continually, continuing indefinitely in the case of axial scanning, or for the dwell time of the scan at position Z for helical scanning.

Alternatively, in accordance with another preferred embodiment of the present invention, the planar slice image is initially reconstructed, based on the attenuation data from sectors 50 through 60, and is then updated for every sector by adding a corresponding difference matrix to the image. The first such difference matrix is produced by (1) pre-processing and interpolating attenuation data acquired in sector 62 to derive effective attenuation values; (2) subtracting therefrom corresponding attenuation values derived from the attenuation data acquired previously in sector 50, and (3) filtering and back-projecting the difference of the sector 62 and sector 50 values to obtain the difference matrix elements. This procedure is repeated for sector 64, and so forth. In this preferred embodiment, it is not necessary to produce and save the partial data matrices for the 30° scan sectors; rather, the pre-processed attenuation data are stored and used in the updating calculation.

It will be appreciated that 30° scan sectors are used in the above preferred embodiments and in Fig. 2 for illustrative purposes only, and any other suitable sector size may be used. In particular, each sector may correspond to a single view, with each such sector having an extent equal to the angular increment between one view and the next, for example, 1°. The slice image

can thus be updated every time a new view is acquired, preferably using a pipeline processing architecture.

It will further be appreciated that the above method is described with reference to 180° reconstruction by way of example only, and it may easily be adapted for use with 360° reconstruction, as well.

By using the above method, with sufficiently small scan sectors, changes in the body of subject 22, such as the flow of a contrast medium or insertion of a biopsy instrument, will appear as quasi-continuous changes in the image displayed by display unit 44. The image will still have a certain lag behind the actual changes, however, due to the pipeline processing delay and to the fact that only one or a few views are changed each time the image is updated. The changing image may also be stored digitally or in analog form, on videotape, for example, for later replay and review.

Fig. 3 is a schematic illustration of a CT slice image 70, acquired by CT scanner 20 in accordance with a preferred embodiment of the present invention. Image 70 shows a cross-sectional slice 72 through the body of subject 22, while a biopsy needle 74 is in the course of being inserted into an organ 76 of the subject. A region of interest (ROI) 78 is defined, either by a user of scanner 20 or automatically by software running in the scanner, to include needle 74 and organ 76. As illustrated in the figure, the area of ROI 78 is roughly one fourth the area of image 70, but a larger or smaller ROI may be defined as needed.

Because ROI 78 is substantially smaller than image 70, the portion of the image within the ROI can be separately updated by image reconstruction circuitry 40 at a higher update rate, and/or with a shorter image lag (as described above), than would be possible for updating the entire image. Therefore, in some preferred embodiments of the present invention, methods of updating the image sector-by-sector, as were described above, are applied to produce a quasi-continuous, time-varying image only of the ROI. This ROI image is used, for example, to track the insertion of needle 74 into organ 76.

In one preferred embodiment of the invention, all of the data in the views is preprocessed and filtered and only the data used for the ROI is projected. In a second preferred embodiment of the invention, only data needed for the ROI (including the data outside the ROI needed for determining the values within the ROI) is processed and interpolated data is used for the missing parts of the views outside the ROI. In a third preferred embodiment of the

invention, assuming that the patient is not moving, is to use the view data outside the ROI from the previous rotation.

Preferably, the time-varying image of ROI 78 is registered with and superimposed on the relatively static image 70.

Alternatively, within the area of image 70, the ROI image may be reconstructed and displayed by itself, while the remainder of the image slice is not reconstructed or displayed.

Further preferably, the position of needle 74 is tracked by CT scanner 20, and the position of ROI 78 is intermittently adjusted in response to changes in the position of needle 74. The position of needle 74 may be tracked using image analysis and tracking software known in the art. Preferably, however, movement of the top of needle 74 is tracked using pre-processed attenuation data acquired from array 30, before performing image reconstruction for the sector. In this way, the time lag between movement of the needle and adjustment of the position of ROI 78 in response thereto is reduced, and the ROI is optimally positioned to include needle 74 and other features of interest, prior to reconstruction.

Preferably, in order to track the top of needle 74 using the pre-processed attenuation data, the ROI image is first reconstructed, and a small sub-region centered on the needle top is defined within this image. The CT values in the ROI are reprojected back to the preprocessed data set, so as to define a data window corresponding to the ROI, and the sub-region values are similarly reprojected to define a corresponding sub-window. Within this sub-window, the maximum value of the data is found, and the window is shifted so that the location of the maximum value is at the center of the window. Note that this "maximum" point corresponds to a minimum in the raw (attenuation) data and a maximum in the preprocessed data. Finding of this maximum is aided by subtracting the data for each view from data acquired previously for the view. The maximum is then found from the difference data. If the patient moves (i.e., if the residuals after subtraction are high) the two sets of data are registered prior to subtraction.

Subsequently, for each new view acquired by circuitry 36, or alternatively, once in every several views, the attenuation data are pre-processed, a new maximum value and the location of the new maximum within the window are found. This new maximum value is compared to the preceding maximum value. The location of the new maximum is compared with the previous location of the maximum and with the direction and velocity of movement of the location of the maximum over the preceding views. If the new maximum value is within a predetermined threshold of the preceding value, and if the location of the new maximum is within

predetermined bounds of the preceding location, based on the direction and velocity of movement, then the window is shifted so that the location of the new maximum value is at the center of the window.

If the difference of the maximum values exceeds the threshold, or if the location of the maximum is outside the predetermined bounds, however, it is assumed that the new maximum value is due to a data artifact. In this case, the window is maintained at its previous position until the maximum value returns to a value within the threshold, or until the ROI image is again reconstructed, and the actual position of needle 74 in the image may be identified.

Alternatively, "raw" attenuation data received from array 30, before preprocessing, may be similarly used in tracking needle 74 using an algorithm similar to that described above. Further alternatively, the needle may be tracked using data that has been preprocessed and filtered, before back-projection to find the CT values.

It will be appreciated that the method described here of finding and tracking the movement of a feature, such as the maximum attenuation value, in image 70 may also be used to detect and correct motion artifacts in the image. For example, a local maximum value of the pre-processed attenuation data, corresponding to an anatomical characteristic of interest, may be identified and tracked. If the location of the maximum value shifts, the CT image may be corrected, using image processing algorithms known in the art, to compensate for the shift.

Fig. 4 is a flow chart schematically illustrating such a method of ROI image reconstruction, in accordance with a preferred embodiment of the present invention. Needle 74 is inserted through the skin of subject 22, at an appropriate location in proximity to organ 76. CT scanner 20 begins to operate, and after tube 28 has scanned at least 180°, a full image 70 is initially reconstructed. The boundaries of ROI 78 are then located relative to image 70, either automatically, as described above, or under the control of an operator of the scanner.

Tube 28 continues to scan through the next sector, having an angular extent Δ, for example, $\Delta=30^{\circ}$ as illustrated in Fig. 2 and described with reference thereto, or $\Delta=1^{\circ}$, as described above, and attenuation data are acquired with respect to the views in this sector. These data are then used to update only the portion of the image within ROI 78, while the remainder of image 70 is left unchanged. The reconstructed ROI section of image 70 is updated on display unit 44. The position of needle 74 in the ROI is identified, and if the needle has substantially shifted relative to its earlier known position, the boundaries of ROI 78 are altered

accordingly. Tube 28 scans the subsequent sectors, and the ROI image is updated, preferably at a rate of 8-10 images per second.

After a suitable period of time t_r, for example 1.5 seconds, the full image 70 is again reconstructed, using the most recently acquired 180^o scan data. The position of needle 74 in this image is similarly identified, and if the needle has substantially shifted relative to its earlier known position, the boundaries of ROI 78 are altered accordingly. Scanning and image reconstruction for the ROI portion of the image then continue, as described above.

It will be appreciated that the principles of the present invention with regard to quasi-continuous ROI image updating may be applied to both axial-scan and helical-scan CT systems. It will further be apparent to those skilled in the art that the principles of the present invention may be applied to CT scanners of various types, including multi-slice scanners, which simultaneously produce multiple image slices, and oblique scanners, which produce image slices along planes at oblique angles relative to the long axis of the subject's body.

Furthermore, it should be understood that, while the invention has been described above with a complete reconstruction being performed, for each segment of acquired data, for bolus tracking and only an ROI is constructed for biopsy needle tracking, in other preferred embodiments of the invention only ROIs are reconstructed for bolus tracking and the entire image is reconstructed for biopsy needle tracking, for each segment of acquired data.

In a preferred embodiment of the invention, preferably using multi-slice scanners (either helical scan or more preferably stationary bed), having multiple rows of detectors, a plurality of slices are acquired simultaneously and preferably simultaneously reconstructed. Such slices may be reconstructed utilizing interpolation between the multiple slices or helical sets of data. As indicated above, the same slices are generated continuously or intermittently using the above described system of partial replacement of data for updating of images.

Figs. 5A and 5B illustrate this method. Fig. 5A shows a view of the same insertion of a biopsy needle as shown in Fig. 3. However, while Fig. 3 shows a single slice, Fig. 5A is a view taken at 90 degrees to that of Fig. 3 showing the outline of four slices 80, 82, 84 and 86 superimposed (as dotted lines) on the schematic body of the patient. Fig. 5B shows the CT image of each of the four slices 80, 82, 84 and 86. As can be seen in the slices, slice 80 shows no sign of needle 74, slice 82 shows a sign of the needle and slices 84 and 86 show strong signs of the needle. It will be noted that the positions of the needles in the slices is different. From

these different positions, it is possible to determine the three dimensional direction of insertion of the needle and the position of its tip.

Based on this information, which is preferably acquired continuously, both the position of the ROI can be easily determined and this information can be used additionally to or instead of the method described in conjunction with Figs 3 and 4, to center the reconstruction ROI in one or all of the slices. Furthermore, in accordance with an especially preferred embodiment of the invention the scanner may be programmed to "look" for signs of the entry of the needle in the next slice (slice 80 in this case) and move the patient such that for future scans the tip of the needle is imaged in one of the central slices.

Thus, in a preferred embodiment of the invention, during biopsy, both the position of the ROI and the position of the multiple slices with respect to the needle tip is automatically changed in response to the determination of the position of the tip of the needle. Alternatively or additionally, the entire image may be periodically recentered in response to the determination of the position of the needle, for example, when the entire image is periodically reconstructed.

While in a preferred embodiment of the invention, the scan is continuous, in other preferred embodiments of the invention, discreet scan are taken, for example, one per second. Alternatively or additionally, the radiation is stopped or the frequency of the scan is reduced if there is no movement for a predetermined time. In some embodiments of the invention, for example when the movement is relatively uniform, low pitch spiral scan, substantially equal to the velocity of the needle tip in the direction of the CT axis, may be performed. Preferably however, this movement is directly controlled, on a step by step basis, by the determination of movement as described above.

Alternatively to automatic movement of the patient to center the needle, in an alternative preferred embodiment of the invention, the physician performing the biopsy is first warned of the need for moving the patient and signifies his approval of the movement before it takes place, for example, by pressing a foot pedal. In this manner, movement of the patent during delicate movement of the biopsy needle is avoided.

It will be understood that the preferred embodiments described above are cited by way of example, and the full scope of the invention is limited only by the claims.

CLAIMS

1. A method for modifying a planar image slice in a CT scanner having a predetermined reconstruction angle, comprising:

reconstructing an image of the slice using initial X-ray attenuation data acquired along an initial scan path sector;

acquiring additional X-ray attenuation data along an additional scan path sector in a vicinity of the axial position of the slice, the sector having an angular extent substantially less than the reconstruction angle; and

modifying the image, to provide a modified image of the slice, responsive to the additional attenuation data.

2. A method according to claim 1, and comprising defining a region of interest within the image slice, wherein modifying the image comprises modifying only a portion of the image corresponding to the region of interest.

3. A method according to claim 2, wherein defining the region of interest comprises identifying an object of interest and altering the region of interest in response to movement of the object.

4. A method according to claim 3, wherein altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest in response to a change is the characteristic.

5. A method according to claim 4, wherein determining the characteristic of the X-ray attenuation data comprises finding a maximum value of the data within a data window corresponding to the region of interest.

6. A method according to claim 5, wherein finding the maximum value of the data comprises pre-processing the data and finding a maximum value of the pre-processed data.

7. A method according to any of the preceding claims, wherein acquiring the data along the initial and additional scan path sectors comprises acquiring multi-slice data along the sectors of the scan path.

8. A method according to any of the preceding claims, wherein acquiring data along the sectors of the scan path comprises acquiring the data along sectors of a helical scan path.

9. A method according to claim 7, wherein acquiring the data along the scan path sectors comprises acquiring the data along sectors of a generally circular scan path substantially within a plane at the axial position of the slice.

10. A method according to any of the preceding claims, wherein modifying the image responsive to the additional attenuation data comprises processing the additional attenuation data and the initial attenuation data to produce an image data matrix and adding the matrix to the image.

11. A method according to claim 10, wherein processing the attenuation data to produce the image data matrix comprises:

back-projecting attenuation values calculated from the additional data, to determine a first preliminary matrix;

back-projecting attenuation values calculated from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector, to determine a second preliminary matrix; and

subtracting the second preliminary matrix from the first preliminary matrix to produce the image data matrix.

12. A method according to claim 10, wherein processing the attenuation data to produce the image data matrix comprises:

calculating initial attenuation values from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector;

calculating additional attenuation values from the additional data;

subtracting the initial attenuation values from the additional attenuation values to determine difference values; and

back-projecting the difference data to produce the image data matrix.

13. A method for producing a CT image of a region of interest within the body of a subject, comprising:

reconstructing a CT image of a slice of the body;

defining the region of interest; and

updating the CT image only in the region of interest, wherein the image of the region of interest encompasses only a portion of the CT image of the slice.

14. A method according to claim 13, and comprising superimposing the CT image of the region of interest on another CT image encompassing a substantially greater portion of the cross-sectional area.

15. A method according to claim 14 wherein the updated image of the region of interest is produced utilizing the method of any of claims 1-12.

16. A method according to any of claims 13-15 wherein the region of interest is determined based on an expectation of change in the CT image in the region of image.

17. A method according to any of claims 13-16, and including identifying an object of interest and wherein defining the region of interest comprises defining the region of interest in response to a determination of the position of the object of interest.

18. A method according to claim 17 and comprising altering the region of interest being reconstructed in response to movement of the object.

19. A method according to claim 18, wherein altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest being reconstructed in response to a change in the characteristic.

20. A method according to claim 19, wherein determining the characteristic of the X-ray attenuation data comprises finding an extremum value of the data within a data window corresponding to the region of interest.

21. A method according to claim 20, wherein finding the extremum value of the data comprises preprocessing the data and finding a maximum value of the pre-processed data.

22. A method according to any of claims 17-21 wherein the CT image is a multi-slice image and wherein the position of the slices are determined based on a determination of the position of the object with respect to the slices.

23. A method of determining an optimal position for multiple CT slices, comprising:
reconstructing the multiple slices based on a first set of data;
determining the position of an object in the slices;
then reconstructing the slices based on the determined position.

24. A method according to any of claims 17-23 wherein the object is a biopsy needle.

25. An imaging method for the determination of the position of a biopsy needle comprising:
reconstructing a CT image from a plurality of views;
determining the position of the biopsy needle in the image; and
determining a region of interest based on the determined position of the biopsy needle.

26. An imaging method according to claim 25 and including periodically updating the image only in the region of interest.

27. An imaging method for imaging a region in a region of interest in which changes are expected comprising:

reconstructing a CT image from a plurality of views; and
periodically modifying the image only in the region of interest.

28. An imaging method according to claim 26 or 27 wherein the image is periodically modified utilizing the method of any of claims 1-12.

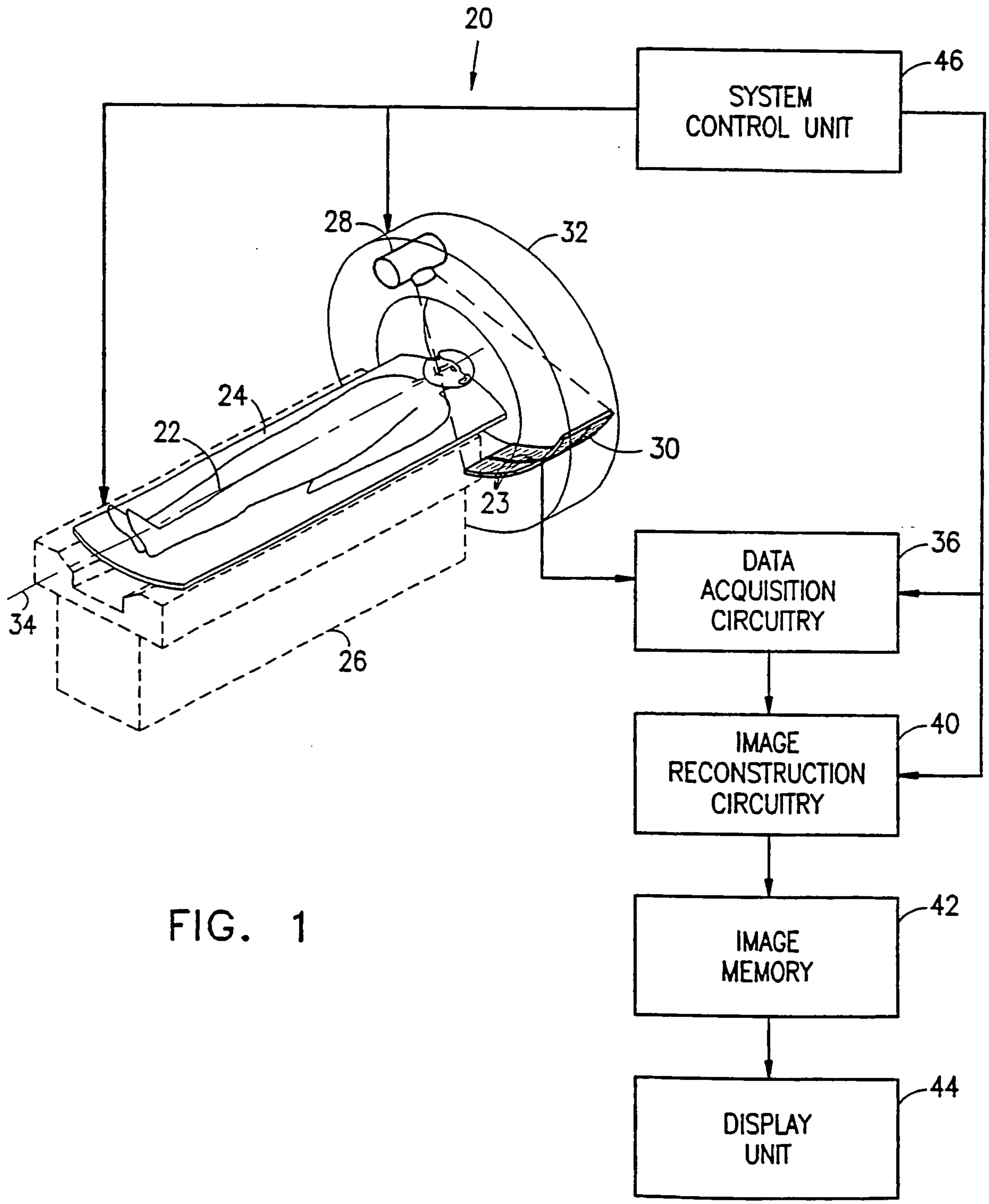
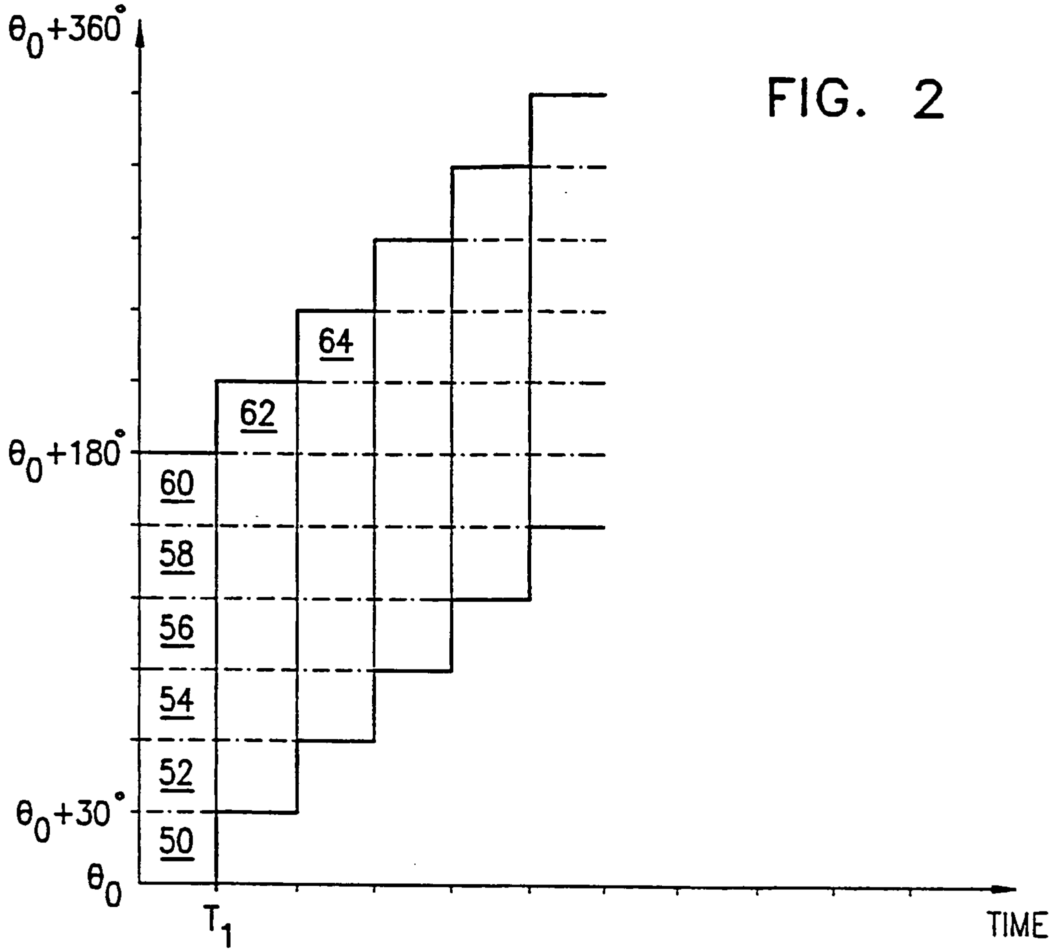
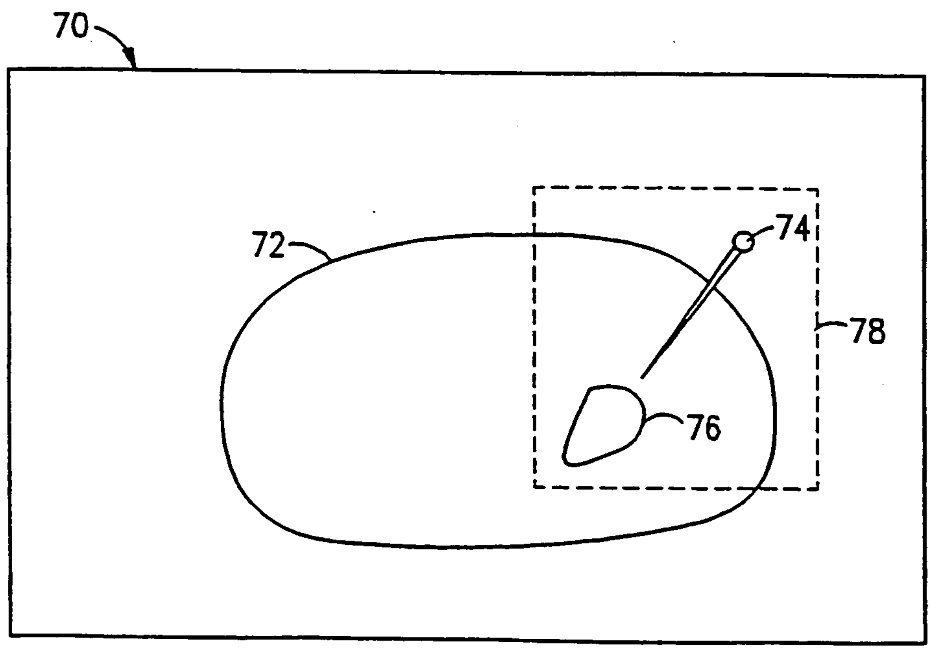

20
SYSTEM CONTROL UNIT
46
28
32
24
22
30
23
DATA ACQUISITION CIRCUITRY
36
34
26
IMAGE RECONSTRUCTION CIRCUITRY
40
IMAGE MEMORY
42
DISPLAY UNIT
44

FIG. 1



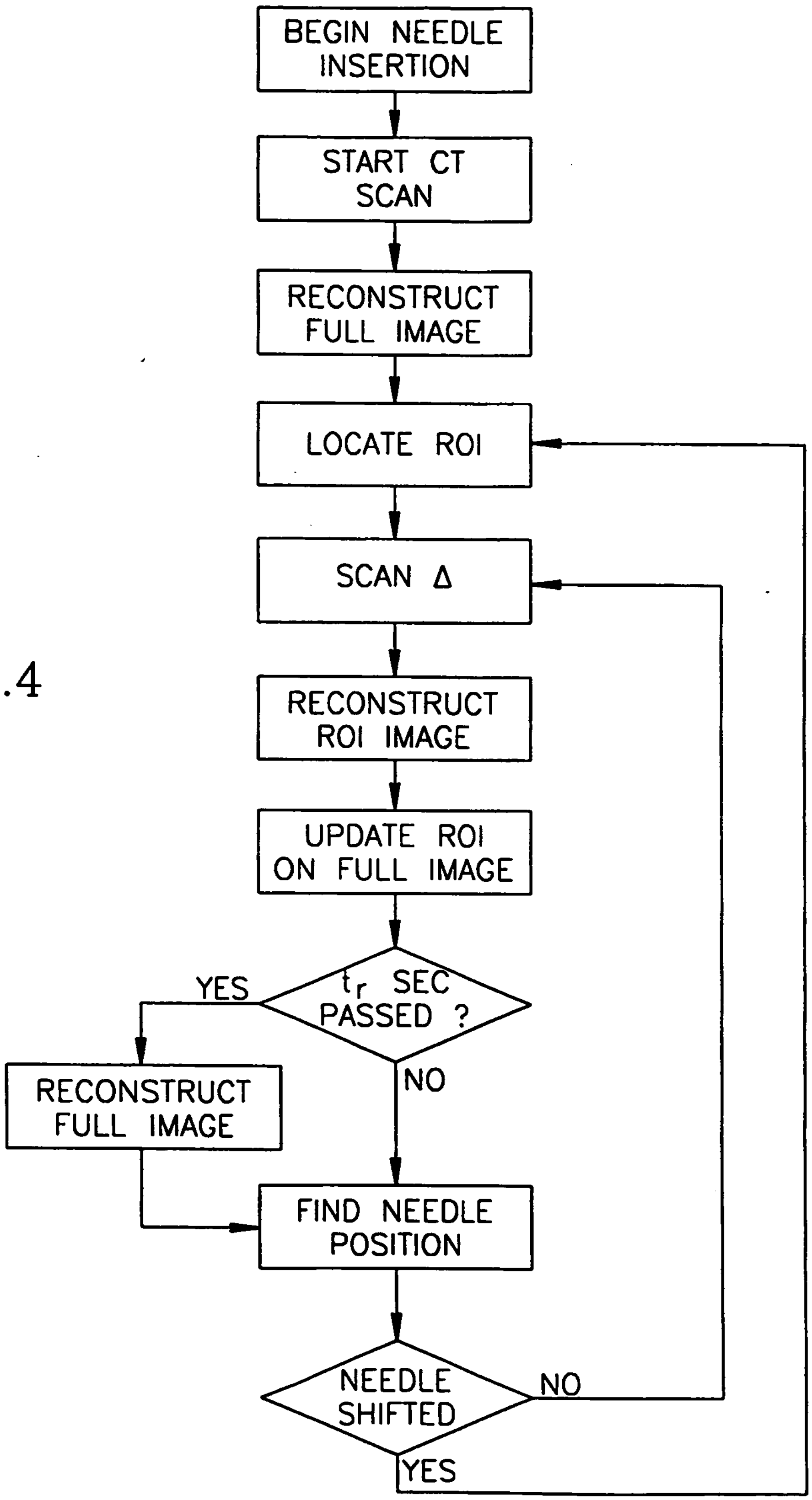
$\theta_0+360°$
$\theta_0+180°$
$\theta_0+30°$
θ_0
64
62
60
58
56
54
52
50
T_1
TIME

FIG. 2



70
72
74
76
78

FIG. 3



BEGIN NEEDLE INSERTION
START CT SCAN
RECONSTRUCT FULL IMAGE
LOCATE ROI
SCAN Δ
RECONSTRUCT ROI IMAGE
UPDATE ROI ON FULL IMAGE
t_r SEC PASSED ?
YES
NO
RECONSTRUCT FULL IMAGE
FIND NEEDLE POSITION
NEEDLE SHIFTED
NO
YES

FIG.4

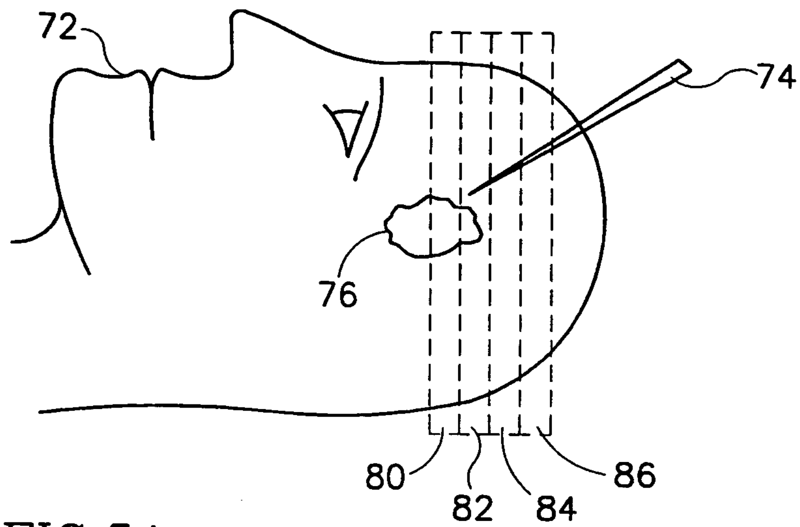


FIG.5A

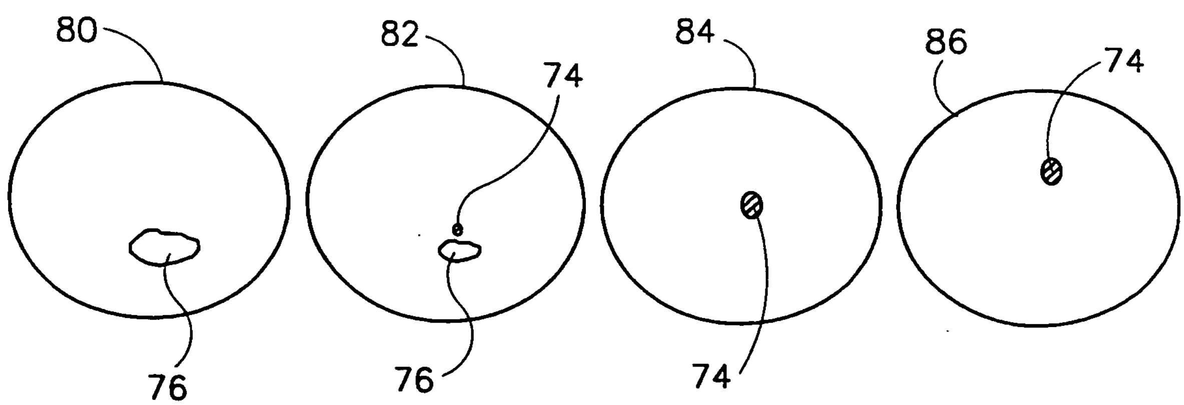


FIG.5B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 98/00074

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61B6/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	FR 2 679 435 A (ELSCINT) 29 January 1993 see the whole document ---	1,7-12, 25-28
A	US 3 866 047 A (EMI) 11 February 1975 see column 2, line 31 - column 11, line 30 ---	2-6, 13-23, 25-28
A	EP 0 662 305 A (PICKER) 12 July 1995 see page 4, line 34 - page 8, line 55 ---	1,7-12, 25-28
A	US 5 291 402 A (GENERAL ELECTRIC) 1 March 1994 see column 7, line 15 - column 10, line 56 --- -/--	1,7-12, 25-28

[X] Further documents are listed in the continuation of box C.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 June 1998	15/06/1998

Name and mailing address of the ISA	Authorized officer
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International Application No
PCT/IL 98/00074

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5 546 439 A (GENERAL ELECTRIC) 13 August 1996 see column 2, line 55 - column 4, line 55 -----	1,7-12, 25-28

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 98/00074

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A1

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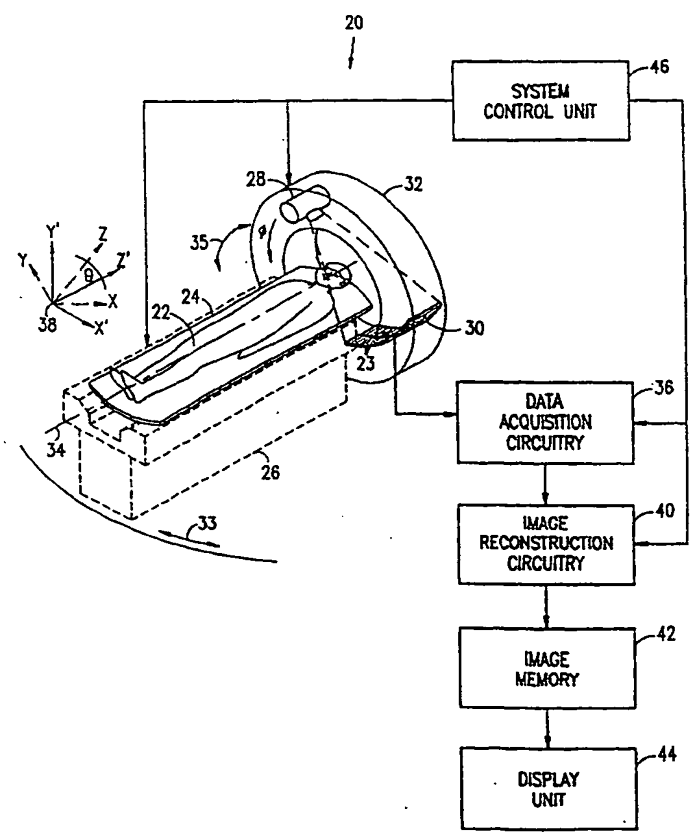
(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: HELICAL SCANNER WITH VARIABLY ORIENTED SCAN AXIS

(57) Abstract

A method for reconstructing images of a subject in a variable-angle helical-scan CT scanner (20), said scanner (20) including an X-ray tube (28), mounted for rotation about a rotation axis, a detector array (30) having one or more rows of detector elements (23) that generates signals responsive to X-rays incident thereon, ad a bed (24), translatable along a translation axis (34), on which bed the subject is placed, the method comprising: angling the translation axis (34) and the rotation axis at an acute angle relative to one another; rotating the X-ray tube (28) about the rotation axis while translating the bed (24) along the translation axis (34) through a plane of rotation of the tube, whereby the X-ray tube (28) describes a helical path relative to the subject; acquiring first and second views of the subject at the same effective rotational angle about the axis of rotation, said views comprising X-ray attenuation data received from elements of the array; producing a planar corrected image slice by interpolation of the data in different views, wherein the data is generated by non-corresponding elements in the different views; and repeating the above steps at respective positions at a plurality of rotational angles of the X-ray tube (28).



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HELICAL SCANNER WITH VARIABLY ORIENTED SCAN AXIS

FIELD OF THE INVENTION

The present invention relates generally to computerized tomographic (CT) imaging, and specifically to multi-slice CT scanners having helical scan paths.

BACKGROUND OF THE INVENTION

Helical-path CT scanners are well known in the art. Generally, such scanners comprise an X-ray tube, mounted on an annular gantry, so as to rotate continuously about a subject being imaged. The subject lies on a table, which is translated continuously through the gantry simultaneously with the gantry's rotation, while X-ray detectors on the opposite side of the subject from the X-ray tube receive radiation transmitted through the subject. The axis of translation of the bed is generally parallel to the long axis of the subject's body, which is typically perpendicular to the plane of rotation of the gantry. Thus, the path of the X-ray tube relative to the subject generally describes a helix about this axis, and X-ray attenuation data received from the X-ray detectors similarly correspond to a series of helically-disposed "views" through the subject. In order to reconstruct planar cross-sectional image slices of the subject, attenuation data for each point in such a planar slice are derived by interpolation between data points in the original helical-path views.

Multi-slice helical-path scanners are similarly known in the art. For example, U.S. patent 5,485,493, which is incorporated herein by reference, describes a multiple detector ring spiral scanner with relatively adjustable helical paths, in which two or more adjacent, parallel slices are acquired along two or more parallel paths simultaneously or sequentially. Data corresponding to planar slices are derived by interpolating between data acquired along the two helical paths. Helical-path scanners in which more than two slices are acquired are also known in the art.

In some scanners, the long axis of the subject's body, along which direction the bed is translated, may be angled relative to the plane of rotation of the gantry, rather than being perpendicular to the axis, as in conventional scanners. This angling typically includes swiveling the bed about a vertical axis, tilting the gantry about a horizontal axis, or a combination of swiveling and tilting. Since the image views are similarly angled relative to the body axis, this angling function is frequently useful in resolving image features that may be difficult to observe in conventional, non-angled scanning. For example, bed swivel may be used in generating longitudinal image slices through the pancreas, and variable gantry tilt may be used to generate images of angled, sectional cuts through the disc spaces of the spine.

When the body axis is tilted, the scanning path of the X-ray tube relative to the axis no longer describes a simple, constant-pitch helix, but rather a more complex spiral figure. In this case, accurate interpolation between different points acquired along a helical path, for the

purpose of reconstructing corrected planar image slices, becomes considerably more complicated. Improper selection of the points for interpolation can produce artifacts in the reconstructed image.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for accurate image reconstruction based on angled helical-scan CT data.

In one aspect of the present invention, angled helical scan data generated during different positions of the gantry (i.e., at different helical positions of the gantry) are combined to form a data set of a view for reconstruction of the image. Due to the geometry of the system this requires that data from non-corresponding elements be combined, where corresponding elements are defined as:

-for 360 degree reconstruction, as elements having the same circumferential position; and

-for 180 degree reconstruction, as elements having the same circumferential distance from an element corresponding to the center of rotation of the gantry, on opposite sides of that element.

In one aspect of the present invention, the helical-scan data are used to reconstruct planar corrected image slices.

In another aspect of the present invention, the CT data comprise multiple-slice CT data, acquired using a multi-row detector array.

In preferred embodiments of the present invention, a variable-angle multi-slice helical-scan CT scanner comprises an X-ray tube, mounted on an annular gantry, which rotates about a bed on which a subject lies, and a detector array. The X-ray tube irradiates the subject from multiple points along its helical trajectory. The detector array comprises one or more parallel rows of X-ray detector elements, each row having a long axis disposed in a generally circumferential direction with respect to the long axis of the subject's body. The detector elements receive radiation that has passed through the subject's body and generate signals responsive to attenuation of the X-rays. The bed is advanced through the gantry along a translation axis that is generally parallel to the long axis of the subject's body. The gantry tilts about a horizontal axis, and the bed swivels, relative to the gantry, about a vertical axis, so that the translation axis of the bed describes an acute angle relative to the axis of rotation of the gantry. The scanner thus performs an angled helical scan over at least a portion of the body.

For each view, i.e., each position of the X-ray tube relative to the body at which X-ray attenuation signals are received from the detector array, the detector array generates a matrix of attenuation signals. Each row in the signal matrix corresponds to a row of elements in the detector array. These signals are normalized and undergo a log operation, as is known in the art. Preferably, the resultant data are then interpolated to generate geometrically-corrected CT

data, which are associated with planar slices through the body. These slices are generally perpendicular to the gantry rotation axis, and are therefore swiveled and/or tilted with respect to the long axis of the body. The corrected data in these planar slices are filtered and back-projected to reconstruct a three-dimensional CT image of the subject's body, using methods known in the art.

Alternatively, instead of interpolating the normalized, log data, the "raw" signals may first be interpolated before undergoing the log operations. Further alternatively, the data may be interpolated after the filtering or after the back-projection operation. It will be appreciated that the principles of the present invention may be applied in these cases, as well.

In preferred embodiments of the present invention, the geometrically-corrected CT data comprise effective attenuation values with respect to each of the planar slices. For each slice, these values are calculated for a plurality of effective detection points, geometrically fixed along a periphery of the slice. Each of the effective attenuation values corresponds to the approximate attenuation that would have been measured along a ray in the planar slice from the X-ray tube to the location of the effective detection point, at a given rotation angle of the tube about the gantry's axis of rotation. The effective attenuation values for each planar slice are calculated for a plurality of rotation angles, preferably covering 360° of rotation about the axis (or more, depending on the helix angle). These values are filtered and back-projected using 360° CT image reconstruction, as is known in the art. Reconstruction using single slices requires at least two rotations and generally more, depending on the helix angle.

Alternatively, 180° reconstruction may be used, as described in an Israel Application filed on even date with the present application, entitled "On-Line Image Reconstruction in Helical CT Scanners, by Elscint Ltd., assignee of the present application, and incorporated herein by reference. In this case, the effective attenuation values for each planar slice are calculated for a plurality covering only about 180° of rotation.

Although the effective detection points are fixed in the plane of the slice, the actual elements of the detector array are generally not in this plane. The positions of the actual elements relative to the effective detection points vary from one tube rotation angle to another, due to the helical shape of the scan path. Therefore, for each of the effective detection points at each rotation angle, two or more detector elements are selected. The elements selected are those whose positions are geometrically closest to the position of the effective detection point at that rotation angle. The actual, measured attenuation data at the element positions are interpolated to calculate the corresponding effective attenuation value at the effective detection point.

In preferred embodiments of the present invention in which a multi-row detector array is used, the actual elements selected for some rotation angles will be mutually-adjacent elements in adjoining, parallel rows of the array. In this case, the effective attenuation values

are interpolated from measured attenuation data from adjacent rows of the signal matrix at a single view, i.e., signals that are acquired while the X-ray tube is at one, given position along the helical scan path.

For other rotation angles, however, and for every rotation angle in preferred embodiments of the present invention in which a single-row detector array is used, the effective attenuation values are interpolated from two or more different signal matrix rows, acquired at different views of the X-ray tube along the helical scan path. In preferred embodiments using 360° reconstruction, the different views are separated by a 360° rotation of the gantry, which is accompanied by translational motion of the bed through the gantry. Additional data may be acquired during further rotations. Alternatively, in 180° reconstruction systems, the different views are separated by 180° of rotation of the gantry. Data can also be acquired from subsequent 180 degree rotations.

In such cases, in which signals from different views are combined, the actual detector elements whose positions are closest to any one of the effective detection points are typically not mutually adjacent elements of the array. The tilt and/or swivel of the scanner introduces an offset, dependent on the rotation angle, between the positions of the elements. In accordance with preferred embodiments of the present invention, the actual detector elements corresponding to each effective detection point are selected based on the tilt and/or swivel angles, the rotation angle, the pitch of the helical path, and other geometrical considerations. Failure to take any of these aspects into account will typically result in artifacts appearing in the CT image.

In some preferred embodiments of the present invention, each effective attenuation value, for each effective detection point, is calculated by weighted interpolation between actual attenuation values derived from two different signal matrix rows. Weighting factors for the interpolation at each point are preferably determined based on the respective distances between the point and the positions of the corresponding actual detector elements. Most preferably, the element closest to the point has the largest weighting factor.

In other preferred embodiments of the present invention, the effective attenuation values are calculated by weighted interpolation between elements in three or more different signal matrix rows. The wider range of interpolation is useful in reducing noise and artifacts in the resultant image. Here, too, the weighting factors are preferably dependent on the distances between each of the effective detection points and the corresponding actual detector elements, as described above.

It will be appreciated that while the preferred embodiments described herein make reference to certain types of medical CT imaging systems, which form an image of the body of a human subject, the principles of the present invention may similarly be applied to other types of CT imaging systems for medical and non-medical purposes.

There is thus provided, in accordance with a preferred embodiment of the invention, a method for reconstructing images of a subject in a variable-angle helical-scan CT scanner, said scanner including an X-ray tube mounted for rotation about a rotation axis, a detector array having one or more rows of detector elements that generate signals responsive to X-rays incident thereon, and a bed, translatable along a translation axis, on which bed the subject is placed, said method comprising:

angling the translation axis and the rotation axis at an acute angle relative to one another;

rotating the X-ray tube about the rotation axis while translating the bed along the translation axis through a plane of rotation of the tube, whereby the X-ray tube describes a helical path relative to the subject;

acquiring first and second views of the subject at the same effective rotational angle about the axis of rotation, said views comprising X-ray attenuation data received from elements of the array;

producing a planar corrected image slice by interpolation of the data in different views, wherein the data is generated by non-corresponding elements in the different views; and

repeating the above steps at respective positions at a plurality of rotational angles of the X-ray tube.

Preferably, producing the planar corrected image slice comprises:

finding a first row of detector elements in one of the first and second views having a longitudinal axis that is closest to a plane of the image slice;

finding a second row of detector elements in one of the first and second views having a longitudinal axis that is next closest to the plane after the first row;

determining a first attenuation value from the first row of elements and a second attenuation value from the second row of elements; and

calculating an effective attenuation value by weighted interpolation of the first and second attenuation values.

In a preferred embodiment of the invention, finding first and second rows of detector elements comprises finding two adjoining rows of the detector array in one of the first and second views.

Preferably, finding first and second rows of detector elements comprises finding a first row in the first view and a second row in the second view, and wherein determining first and second attenuation values comprises determining an offset between the first and second rows. In a preferred embodiment of the invention, determining the offset between the first and second rows comprises determining an offset dependent on the rotational angle of the X-ray tube. Preferably, determining the offset between the first and second rows comprises determining an offset dependent on the acute angle between the translation axis and the

rotation axis.

In a preferred embodiment of the invention determining the first attenuation value comprises computing a weighted sum of attenuation data received from two or more detector elements in the first row. Preferably, determining the second attenuation value comprises computing a weighted sum of attenuation data received from two or more detector elements in the second row.

In a preferred embodiment of the invention, calculating the effective attenuation value by weighted interpolation comprises determining weighting factors dependent on the rotational angle of the X-ray tube. Alternatively or additionally calculating the effective attenuation value by weighted interpolation preferably comprises determining weighting factors dependent on the acute angle between the translation axis and the rotation axis.

In a preferred embodiment of the invention determining the first attenuation value at a point in the view comprises finding the two elements in the first row whose centroids are closest to the point and calculating an effective row element attenuation value based on signals received from the two elements. Alternatively or determining the second attenuation value at a point in the view preferably comprises finding the two elements in the second row whose centroids are closest to the point and calculating an effective row element attenuation value based on signals received from the two elements.

In a preferred embodiment of the invention the method includes finding one or more additional rows of detector elements, parallel to the first and second rows, and determining one or more additional attenuation values from the additional rows, wherein calculating an effective attenuation value in the planar slice comprises calculating the effective attenuation value by weighted interpolation of the additional values with the first and second attenuation values.

In a preferred embodiment of the invention the method comprises acquiring one or more additional views at the same effective rotational angle as the first and second views, wherein producing the planar corrected image slice by interpolation of the data in the views comprises combining the one or more additional views with the first and second views by weighted interpolation of the data.

In a preferred embodiment of the invention, the detector array has one row of elements. In an alternative preferred embodiment of the invention, the detector array has more than one row of elements.

There is further provided, in accordance with a preferred embodiment of the invention, a method for reconstructing images of a subject in a variable-angle helical-scan CT scanner, said scanner including an X-ray tube mounted for rotation about a rotation axis, a detector array having one or more rows of detector elements that generate signals responsive to X-rays incident thereon, and a bed, translatable along a translation axis, on which bed the subject is

placed, the method comprising:

angling the translation axis and the rotation axis at an acute angle relative to one another;

rotating the X-ray tube about the rotation axis while translating the bed along the translation axis through a plane of rotation of the tube, whereby the X-ray tube describes a helical path relative to the subject;

acquiring first and second views of the subject at first and second positions along the helical path of the X-ray tube, both positions being at the same effective rotational angle about the axis of rotation, said views comprising X-ray attenuation data received from elements of the array;

producing a planar corrected image slice by interpolation of the data in different views; and

repeating the above steps at respective positions at a plurality of rotational angles of the X-ray tube,

wherein determining a value for interpolation at a point in the view comprises finding the two elements in a row whose centroids are closest to the point and calculating an effective row element attenuation value based on signals received from the two elements.

In a preferred embodiments of the above described invention acquiring said first and second views comprises acquiring said first and second views at first and second positions along the helical path of the X-ray tube.

The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of a variable-angle, multi-slice helical-scan CT scanner, operative in accordance with a preferred embodiment of the present invention;

Fig. 2A is a schematic representation of detector elements in an array over two successive 360 degree rotations, incorporated in the CT scanner of Fig. 1, at a first rotation angle of the scanner (at zero or 180 degrees), illustrating geometrical principles applied in a preferred embodiment of the present invention;

Fig. 2B is a schematic representation of the detector elements of Fig. 2A, at a second rotation angle (90 or 270 degrees) of the scanner, further illustrating geometrical principles applied in a preferred embodiment of the present invention; and

Fig. 3 is a flow chart illustrating a method for reconstruction of a CT image, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to Fig. 1, which shows a CT scanner 20, operative in accordance with a preferred embodiment of the present invention. Scanner 20 comprises a bed

24, supported by a base 26, on which bed a subject 22 lies while his body is being imaged by the scanner. Scanner 20 further comprises an X-ray tube 28, which irradiates subject 22, and a detector array 30, which receives X-rays from tube 28 and generates signals responsive to the attenuation of the X-rays in passing through the subject's body. Preferably, array 30 comprises multiple, parallel rows of X-ray detector elements 23. Tube 28 and array 30 are mounted on an annular gantry 32, so as to rotate about subject 22. Simultaneously, bed 24 is advanced through gantry 32 along axis 34, which is generally parallel to the long axis of the subject's body.

Scanner 20 as pictured in Fig. 1 is of a type known in the art as a third-generation CT-scanner, characterized in that both tube 28 and detector array 30 rotate about subject 22. It will be appreciated, however, that the principles of the present invention and the methods of image reconstruction to be described below are equally applicable to other types of CT scanners, for example, fourth-generation CT scanners, which include annular detector arrays that are generally rotationally stationary, while the X-ray tube rotates about the subject.

Scanner 20 may be configured so that axis 34 is substantially perpendicular to the plane of rotation of gantry 32. Additionally, axis 34 may preferably be angled relative to the gantry plane, for example, by swiveling bed 24 horizontally, in a direction indicated by arrow 33, and/or by tilting gantry 32 about a generally horizontal tilt axis in a direction indicated by arrow 35. Preferably, the tilt and swivel angles are controlled by a system control unit 46, which also regulates the rotation of the gantry and the advance of the bed.

For clarity in the following discussion, we identify two sets of Cartesian coordinate axes 38 in Fig. 1: rotating, gantry-fixed axes X, Y, Z, indicated by dashed arrows, and bed-fixed axes X', Y', Z', indicated by solid arrows. The Z-axis is substantially the axis of rotation of gantry 32 and is fixed in space. The Y-axis points from the center of rotation of the gantry to tube 28 and rotates therewith, and the X-axis is, therefore, generally parallel to the long axis of array 30. The Z'-axis is parallel to bed axis 34. Axis Y' points vertically upward, parallel to the swivel axis (if any) of bed 24, and axis X' is thus generally horizontal. Axis Z' is angled relative to axis Z by a two-dimensional angle θ, which takes into account both the tilt of gantry 32 and the swivel of bed 24. The angle of rotation of the gantry ϕ is taken to be zero when tube 28 is at its uppermost rotational position.

As tube 28 rotates and bed 24 advances, the tube describes a generally spiral path around axis 34. Preferably, bed 24 moves with substantially constant velocity, so that the spiral path has a constant pitch. At each "view," i.e., at each of a plurality of selected locations of tube 28 along this path, data acquisition circuitry 36 acquires a matrix of attenuation signals. The elements of this matrix are signals received from each detector element 23 of array 30 responsive to X-ray attenuation along a ray from tube 28 to the detector element. Each such

matrix may comprise a plurality of rows, wherein each such row corresponds to signals received at one of the plurality of views from one of the multiple rows of array 30.

For each view, data acquisition circuitry 36 performs signal normalization and logarithm operations, as are known in the art, to derive an X-ray attenuation value corresponding to each of elements 23. Image reconstruction circuitry 40 receives these values and performs interpolation and other data processing operations, as will be described below, to convert the views acquired during the helical scan into corrected, planar image slices at desired positions along the Z-axis. These planar image slices may then be used to reconstruct three-dimensional or other CT images of the body of subject 22, using methods known in the art. Preferably, these images are stored in image memory 42, displayed by display unit 44, and may be otherwise printed and/or processed as is known in the art. The data and/or images may also be stored for later reconstruction and or display.

Fig. 2A schematically represents the positions and detection areas of detector elements 23 in array 30 in two views, labeled "VIEW 1" and "VIEW 2." The two views are acquired at the same effective rotational angle of gantry 32, i.e., at rotation angles $\phi = 0^{o}$ and $\phi = 360^{o}$, respectively. (The same results apply for $\phi = 180^{o}$ and $\phi = 540^{o}$ In the description that follows and in the claims, two views will be said to be acquired at the same effective rotational angle when they are acquired at gantry positions separated by an integer number of full, 360^{o} rotations, for the case of 360^{o} reconstruction, or by an integer number of half, 180^{o} rotations, for 180^{o} reconstruction.

For simplicity of explanation, array 30 is shown as having only two parallel rows 27 and 29 of detectors 23, each row comprising M detector elements 23, labeled $D_{11}..D_{1M}$ and $D_{21}..D_{2M}$ respectively. Gantry 32 is assumed to be tilted by angle θ relative to bed 24, while the swivel angle of bed 24 is substantially zero. It will be understood, however, that the principles of the method to be described below are equally applicable to multi-slice arrays having greater or lesser numbers of rows, and to configurations of scanner 20 in which bed 24 has a non-zero swivel angle. Similarly, the method applies generally for any rotational angle ϕ of tube 28, as will be shown below.

In an exemplary embodiment of the invention, to acquire a matrix of attenuation signals for the first of the two views, VIEW 1, the bed 24 is advanced through gantry 32 so that array 30 is centered at a position marked Z_1 in the figure. As the bed continues to advance in the positive Z'-direction, gantry 32 makes a complete, 360^{o} revolution about the bed. The gantry returns to the rotational position that it held in VIEW 1 when the array is centered at position Z_2, where the signal matrix for VIEW 2 is acquired. Because VIEW 1 and VIEW 2 are acquired at the same effective rotational angle $\phi = 0$, and zero swivel angle, the positions of rows 27 and 29 in the two views, as shown in Fig. 2A, are mutually substantially aligned.

A planar image slice is to be reconstructed in a plane parallel to the rotation plane of gantry 32, at the position marked Z_0. In the situation illustrated by Fig. 2A, there is no view acquired that includes a row 27 or 29 centered at Z_0. A corrected slice at this position is reconstructed by choosing and interpolating between a plurality of effective detection points around a periphery of the corrected slice, at a radial distance from the Z-axis that is generally equal to the distance of the detection points in rows 27 and 29 of array 30 from the Z axis. An effective attenuation value is determined at each of the points by interpolating between the X-ray attenuation data received from two or more elements 23 in different rows 27 and 29 and/or in different views, VIEW 1 and VIEW 2. The effective attenuation at each of the plurality of points corresponds, in close approximation, to the attenuation that would be measured along a line in the X-Y plane from X-ray tube 28 to the point.

For example, to determine an effective attenuation value at a point 50, which is located on the periphery of the slice at Z_0, at a displacement R along the X axis as shown, a weighted sum is taken of data input from element D_{2i} in VIEW 1 and data input from its adjacent element D_{1i} in VIEW 2. Generally the weighting factors for the two input elements will vary inversely with the relative distances of the respective centroids of the two elements from point 50. These weighting factors will generally be the same, however, for all points (at varying values of R) along the periphery of the slice at position Z_0. If the fan beam data is rebinned into parallel beam data an adjustment of the weighting for different positions on the fan may be desirable. However, such adjustments generally quite small.

In alternative embodiments of the present invention, greater numbers of input elements may be included in the weighted sum to determine the effective attenuation value at point 50, so as to improve the quality of the image, using Z-axis weighting or filtering methods known in the art. Furthermore, the attenuation data from array 30 may be reformatted, as is known in the art, from the fan beam format in which the attenuation signals are received, as exemplified in Fig. 1, to a parallel beam format, for the purpose of improving the quality of the resultant CT image. It will be understood that the methods described herein with reference to elements 23 and the unreformatted data received are preferably applied to such reformatted data samples.

Although point 50 at position Z_0 is shown in Fig. 2A as being midway between rows 27 and 29, it will be understood that the method described above may be applied to determine effective attenuation values at any Z-position in between rows 27 and 29 or within the detection area of one of the rows. In the particular case in which the Z-position of point 50 is substantially centered within one of the rows, the effective attenuation value at the point is preferably derived directly from the attenuation data in that row. Alternatively, the effective attenuation value may be calculated by taking a weighted average of the data in the row within which point 50 is centered with data from neighboring rows on either side thereof.

Fig. 2B schematically represents the positions of detector elements 23 in the same configuration of scanner 20 as in Fig. 2A, i.e., with tilt angle θ. Two views, labeled VIEW 1' and VIEW 2', are acquired in the manner described above regarding VIEW 1 and VIEW 2, with tube 28 taken to be at rotational angles $\phi = 90^o$ and $\phi = 450^o$, respectively. Viewed from this substantially horizontal view angle, the Z-axis of gantry 32 is seen to be tilted with respect to the Z'-axis of bed 24, and the positions of elements 23 of array 30 in the two views are mutually offset along the X-axis. Moreover, since bed 24 has advanced along the Z'-axis direction relative to its position in VIEW 1 and VIEW 2, the X-axis, coinciding with the plane of the image to be reconstructed, is shown in Fig. 2B as having shifted in the Z'-direction.

For the purposes of the description that follows, we note further in Fig. 2B that elements 23 of array 30 are taken to have a common pitch P. Each of the two rows 27 and 29 of array 30 has a respective longitudinal axis passing substantially through the centroids of the elements in the row, which axes are marked 5θθ2a and 54a respectively for VIEW 1', and 52b and 54b respectively for VIEW 2'. Bed 24 advances through gantry 32 at a velocity V, and the period during which the gantry makes a complete, 360° rotation is Δt, so that between VIEW 1' and VIEW 2', array 30 advances by a distance ΔZ' along the Z'-axis, as shown in Fig. 2B, given by $\Delta Z' = V \cdot \Delta t$. In the plane of the gantry, the distance is $\Delta Z = V \cdot \Delta t \cos \theta$.

Fig. 3 is a flow chart illustrating a method for calculating effective attenuation values in a planar image slice in the X-Y plane, generally perpendicular to the rotation axis of gantry 32, in accordance with a preferred embodiment of the present invention. The key steps in this method involve taking a plurality of effective detection points in the periphery of the plane, as described above, and then selecting and calculating appropriate input data from elements 23 to determine the effective attenuation values at each of the plurality of points.

The process of selecting and calculating the effective attenuation values is repeated at each of a plurality of gantry rotation angles φ. For each rotation angle, at least two attenuation signal matrices, from respective views at angles φ and $\phi+360^o$ (or φ and $\phi+180^o$ in the case of 180^o reconstruction), are used in the calculation. In order to avoid the creation of image artifacts, for each angle it is generally necessary to select different input elements to correspond to each effective detection point and to determine appropriate weighting factors to use in interpolatively calculating the effective attenuation values at the points.

For example, when $\phi=90^o$, as shown in Fig. 2B, image reconstruction circuitry 40 receives the coordinates of rows 27 and 29 in VIEW 1' and VIEW 2' from system control unit 46 (shown in Fig. 1). The circuitry compares the Z-axis position of the plane for reconstruction, marked by the X-axis, with the positions of rows 27 and 29 to determine which of axes 52a, 54a, 52b and 54b is closest to the plane. In the case shown in Fig. 2B, axis 52b in VIEW 2' is the closest. If two axes are equidistant from the plane, then either may be chosen as the closest, and the remainder of the calculation is substantially unaffected.

Next the circuitry determines which of the remaining row axes is the next closest to the point. For some rotation angles ϕ, the next closest axis is from the same view as the closest axis. Such would be the case, for example, with regard to a plane passing through point 56 in Fig. 2B, for which axis 54b is the next closest. The corrected attenuation value at point 56 is then determined simply by weighted interpolation between elements $D_{1,k}$ and $D_{2,k}$, with the weighting factors dependent on the relative distances of axes 52b and 54b from point 56.

Returning now to consider point 55 on the X-axis, the next closest axis after axis 52b is axis 54a of row 29 in VIEW 1'. Element $D_{2,k+2}$ in VIEW 1' is closest to point 55 in its detection area, but the border between this element and its neighboring element in array 30, $D_{2,k+1}$, is offset relative to the borders between element $D_{1,k}$ and its neighboring elements in VIEW 2'. In order to avoid producing artifacts in the image that is reconstructed by circuitry 40, an effective row element attenuation value is calculated by weighted interpolation between the attenuation values of elements $D_{2,k+1}$ and $D_{2,k+2}$ in VIEW 1'. Weighting factors for this interpolation are calculated based on the relative offset of elements 23 of array 30 between VIEW 1' and VIEW 2'. This effective row element attenuation value is then combined by weighted interpolation with the value of the first input element (in this case $D_{1,k}$ in VIEW 2') to compute the effective attenuation value at point 55.

The following formula is a general expression for calculating the effective row element attenuation value V_{eff} for the case where the first element $D_{1,k}$ is from VIEW 2' and V_{eff} is to be determined by interpolation among the attenuation values $V_{2,i}$ and $V_{2,i+1}$ received respectively from two elements $D_{2,i}$ and $D_{2,i+1}$ in VIEW 1':

$$V_{eff} = V_{2,k} \quad \text{for } M-1-\Delta Z'\cdot\sin\Theta/P \leq k < M-1$$

$$V_{eff} = W_m V_{2,m} + W_{m+1} V_{2,m+1} \quad \text{for } 0 \leq k < M-1-\Delta Z'\cdot\sin\Theta/P$$

where $m = \mathrm{INT}[k + \Delta Z'\cdot\sin\Theta/P]$, and W_m and W_{m+1} are interpolation weighting factors, and INT(x) is the greatest integer in x. Although for the specific case illustrated in Fig. 2B, $\Theta = \theta$, where θ is the tilt angle of bed 24, the formulas above may be generalized to include both the swivel angle of bed 24 and the tilt angle of gantry 32 by substituting:

$$\Theta = \arcsin[\sin(\text{swivel})\cdot\cos\phi + \sin(\text{tilt})\cdot\sin\phi].$$

Preferably, the weighting factors W_m and W_{m+1} are calculated for linear interpolation, for example by the following formulas:

$$W_m = \Delta Z' \cdot \sin\Theta / P - \mathrm{INT}(\Delta Z' \cdot \sin\Theta / P)$$

$$W_{m+1} = 1 - W_m$$

Alternatively, the weighting factors may be calculated using a shift function, for example:

$$W_m = \mathrm{INT}\{0.5 + \Delta Z' \cdot \sin\Theta / P - \mathrm{INT}(\Delta Z' \cdot \sin\Theta / P)\}$$

$$W_{m+1} = 1 - W_m$$

Other weighting factors may similarly be used, such as, but not limited to utilizing more elements per row, depending, *inter alia*, on geometrical considerations in the CT scanner.

Similar formulas may be straightforwardly derived from the above equations for cases in which the first element (i.e., the element nearest to the point of interest in the planar corrected slice) is in VIEW 1', and an effective row element attenuation value must be determined by interpolation between elements in the preceding VIEW 2'.

In other preferred embodiments of the present invention, effective row attenuation values are calculated for the row whose axis is nearest the plane of the planar corrected slice, as well as for the row whose axis is next-nearest the plane. In this case, for example, an effective row attenuation value for row 27 could be calculated with respect to point 55 by weighted interpolation between elements $D_{1,k}$ and $D_{1,k-1}$ in VIEW 2'. The value would then be combined by weighted interpolation with the value of V_{eff} determined for row 29 in VIEW 1', as described above, to calculate the effective attenuation value for point 55.

Additionally or alternatively, in some preferred embodiments of the present invention, data from more than two rows may be combined by interpolation to determine effective attenuation values for a planar corrected slice. For example, data from both of rows 27 and 29 in both VIEW 1' and VIEW 2' could be thus combined, and data from additional views at $\phi = +360 \cdot N^o$ (or $+180 \cdot N^o$ for 180 degree reconstruction) could also be introduced, in determining the effective attenuation value for point 55. In these preferred embodiments, the respective offset of each of the rows is taken into account, and interpolative weighting factors are calculated accordingly, based on the principles described above.

It will be appreciated that although the above preferred embodiments have been described, for simplicity, in terms of a two-slice scanner, based on detector array 30 having two rows of elements 27 and 29, the principles of the present invention are equally applicable

to single-slice scanners, as well as to multi-slice scanners and arrays having three, four or more rows of elements.

Furthermore, the above preferred embodiments have been described with reference to 360^{o} image reconstruction, in which the planar corrected slice is produced by interpolating between two views taken at adjacent positions of X-ray tube 28, between which the tube has made a full circle of rotation around bed 24. It will be appreciated, however, that the inventive principles described above may similarly be applied to 180^{o} image reconstruction systems, as are known in the art. In such systems, the effective attenuation values are calculated from data acquired in two views that are 180^{o} apart. Generally, an additional offset is introduced between array elements 23 in the two views, and the formulas given above for calculating V_{eff} are preferably corrected to account for this offset.

It will also be appreciated that while the above preferred embodiments have been described with regard to medical CT imaging system 20, which is pictured as a third-generation system, forming an image of the body of human subject 22, the principles of the present invention may similarly be applied to fourth-generation and other types of CT imaging systems for medical and non-medical purposes.

It will additionally be appreciated that the preferred embodiments described above are cited by way of example, and the full scope of the invention is limited only by the claims.

CLAIMS

1. A method for reconstructing images of a subject in a variable-angle helical-scan CT scanner, said scanner including an X-ray tube mounted for rotation about a rotation axis, a detector array having one or more rows of detector elements that generate signals responsive to X-rays incident thereon, and a bed, translatable along a translation axis, on which bed the subject is placed, said method comprising:

angling the translation axis and the rotation axis at an acute angle relative to one another;

rotating the X-ray tube about the rotation axis while translating the bed along the translation axis through a plane of rotation of the tube, whereby the X-ray tube describes a helical path relative to the subject;

acquiring first and second views of the same effective rotational angle about the axis of rotation, said views comprising X-ray attenuation data received from elements of the array;

producing a planar corrected image slice by interpolation of the data in different views, wherein the data is generated by non-corresponding elements in the different views; and

repeating the above steps at respective positions at a plurality of rotational angles of the X-ray tube.

2. A method according to claim 1, wherein producing the planar corrected image slice comprises:

finding a first row of detector elements in one of the first and second views having a longitudinal axis that is closest to a plane of the image slice;

finding a second row of detector elements in one of the first and second views having a longitudinal axis that is next closest to the plane after the first row;

determining a first attenuation value from the first row of elements and a second attenuation value from the second row of elements; and

calculating an effective attenuation value by weighted interpolation of the first and second attenuation values.

3. A method according to claim 2, wherein finding first and second rows of detector elements comprises finding two adjoining rows of the detector array in one of the first and second views.

4. A method according to claim 2 or 3, wherein finding first and second rows of detector elements comprises finding a first row in the first view and a second row in the second view, and wherein determining first and second attenuation values comprises determining an offset between the first and second rows.

5. A method according to claim 4, wherein determining the offset between the first and second rows comprises determining an offset dependent on the rotational angle of the X-ray tube.

6. A method according to claim 4 or 5, wherein determining the offset between the first and second rows comprises determining an offset dependent on the acute angle between the translation axis and the rotation axis.

7. A method according to any of claims 4-6, wherein determining the first attenuation value comprises computing a weighted sum of attenuation data received from two or more detector elements in the first row.

8. A method according to any of claims 4-7, wherein determining the second attenuation value comprises computing a weighted sum of attenuation data received from two or more detector elements in the second row.

9. A method according to any of claims 2-8, wherein calculating the effective attenuation value by weighted interpolation comprises determining weighting factors dependent on the rotational angle of the X-ray tube.

10. A method according to any of claims 2-9, wherein calculating the effective attenuation value by weighted interpolation comprises determining weighting factors dependent on the acute angle between the translation axis and the rotation axis.

11. A method according to any of claims 2-10, wherein determining the first attenuation value at a point in the view comprises finding the two elements in the first row whose centroids are closest to the point and calculating an effective row element attenuation value based on signals received from the two elements.

12. A method according to any of claims 2-11, wherein determining the second attenuation value at a point in the view comprises finding the two elements in the second row whose centroids are closest to the point and calculating an effective row element attenuation value based on signals received from the two elements.

13. A method according to any of claims 2-12, and comprising finding one or more additional rows of detector elements, parallel to the first and second rows, and determining one or more additional attenuation values from the additional rows, wherein calculating an effective attenuation value in the planar slice comprises calculating the effective attenuation value by weighted interpolation of the additional values with the first and second attenuation values.

14. A method according to any of the preceding claims, and comprising acquiring one or more additional views at the same effective rotational angle as the first and second views,

wherein producing the planar corrected image slice by interpolation of the data in the views comprises combining the one or more additional views with the first and second views by weighted interpolation of the data.

15. A method according to any of the preceding claims wherein the detector array has one row of elements.

16. A method according to any of the preceding claims wherein the detector array has more than one row of elements.

17. A method for reconstructing images of a subject in a variable-angle helical-scan CT scanner, said scanner including an X-ray tube mounted for rotation about a rotation axis, a detector array having one or more rows of detector elements that generate signals responsive to X-rays incident thereon, and a bed, translatable along a translation axis, on which bed the subject is placed, the method comprising:

angling the translation axis and the rotation axis at an acute angle relative to one another;

rotating the X-ray tube about the rotation axis while translating the bed along the translation axis through a plane of rotation of the tube, whereby the X-ray tube describes a helical path relative to the subject;

acquiring first and second views of the subject at the same effective rotational angle about the axis of rotation, said views comprising X-ray attenuation data received from elements of the array;

producing a planar corrected image slice by interpolation of the data in different views; and

repeating the above steps at respective positions at a plurality of rotational angles of the X-ray tube,

wherein determining a value for interpolation at a point in the view comprises finding the two elements in a row whose centroids are closest to the point and calculating an effective row element attenuation value based on signals received from the two elements.

18. A method according to any of the preceding claims wherein acquiring said first and second views comprises acquiring said first and second positions at first and second positions along the helical path of the X-ray tube.

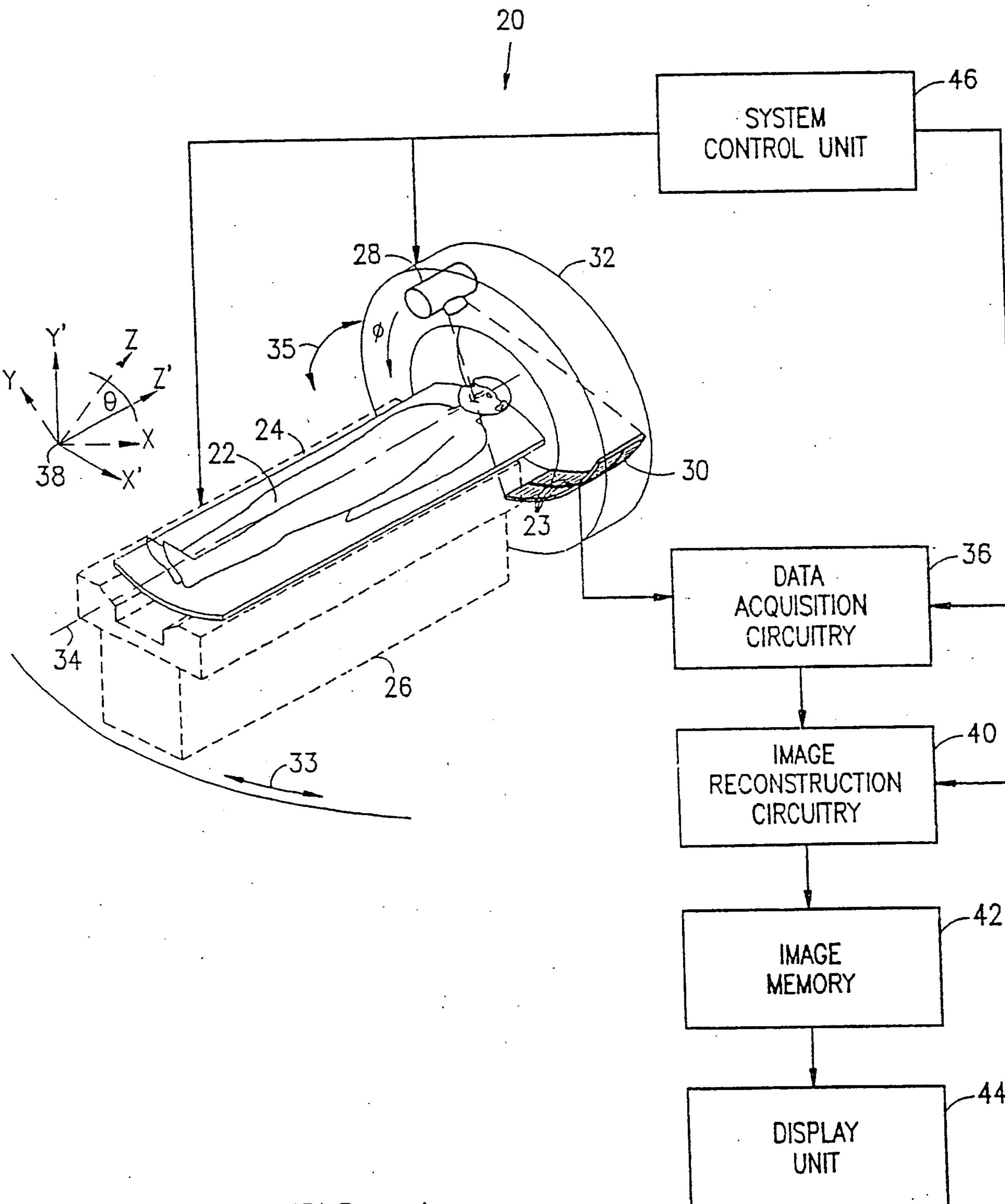

20
SYSTEM CONTROL UNIT
46
28
32
35
φ
Y'
Z
Y
Z'
θ
X
X'
38
24
22
30
23
DATA ACQUISITION CIRCUITRY
36
34
26
IMAGE RECONSTRUCTION CIRCUITRY
40
33
IMAGE MEMORY
42
DISPLAY UNIT
44

FIG. 1

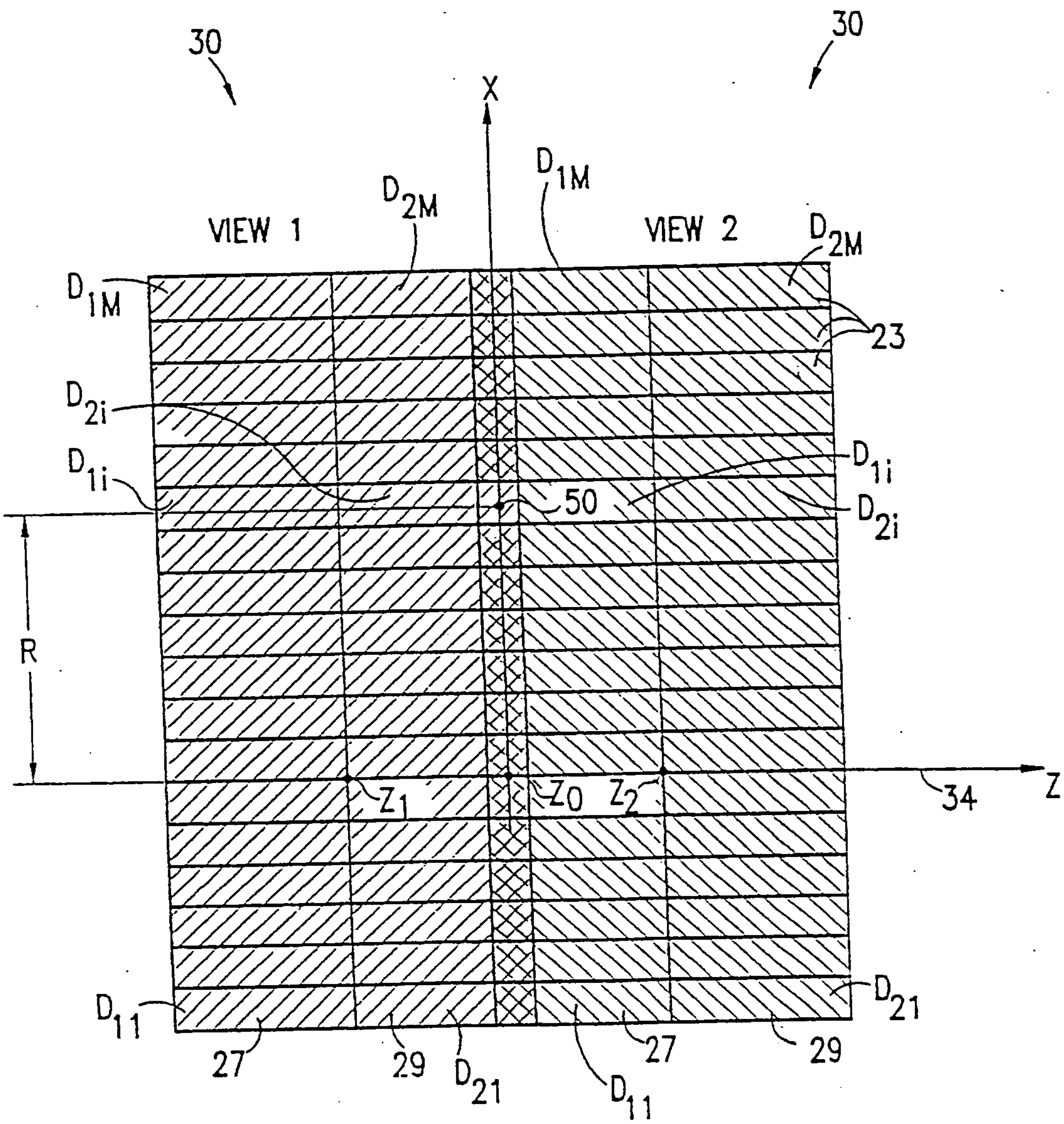

30
30
X
VIEW 1
VIEW 2
D_{2M}
D_{1M}
D_{1M}
D_{2M}
23
D_{2i}
D_{1i}
D_{1i}
50
D_{2i}
R
Z_1
Z_0
Z_2
34
Z
D_{11}
D_{21}
27
29
D_{21}
D_{11}
27
29

FIG. 2A

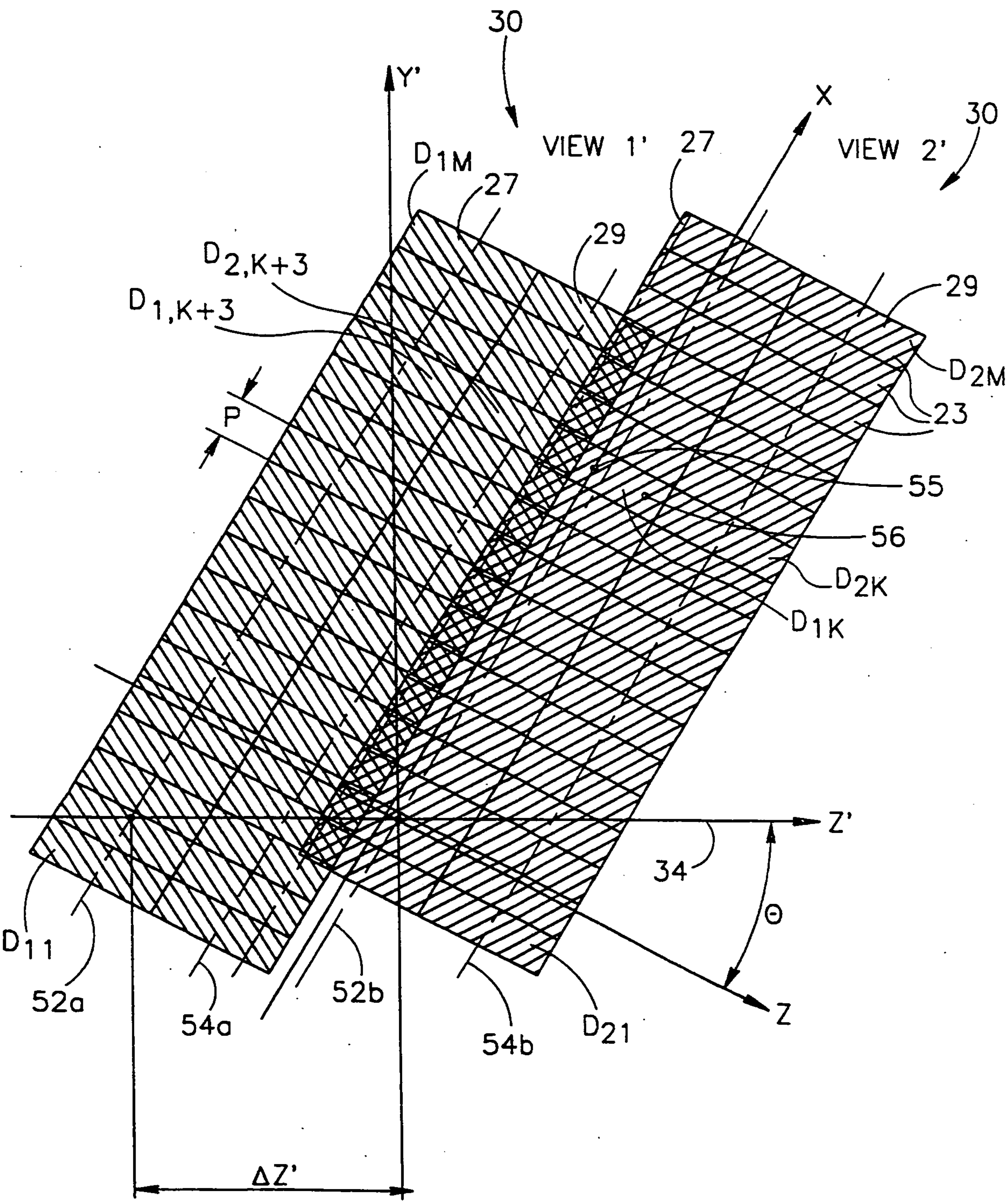
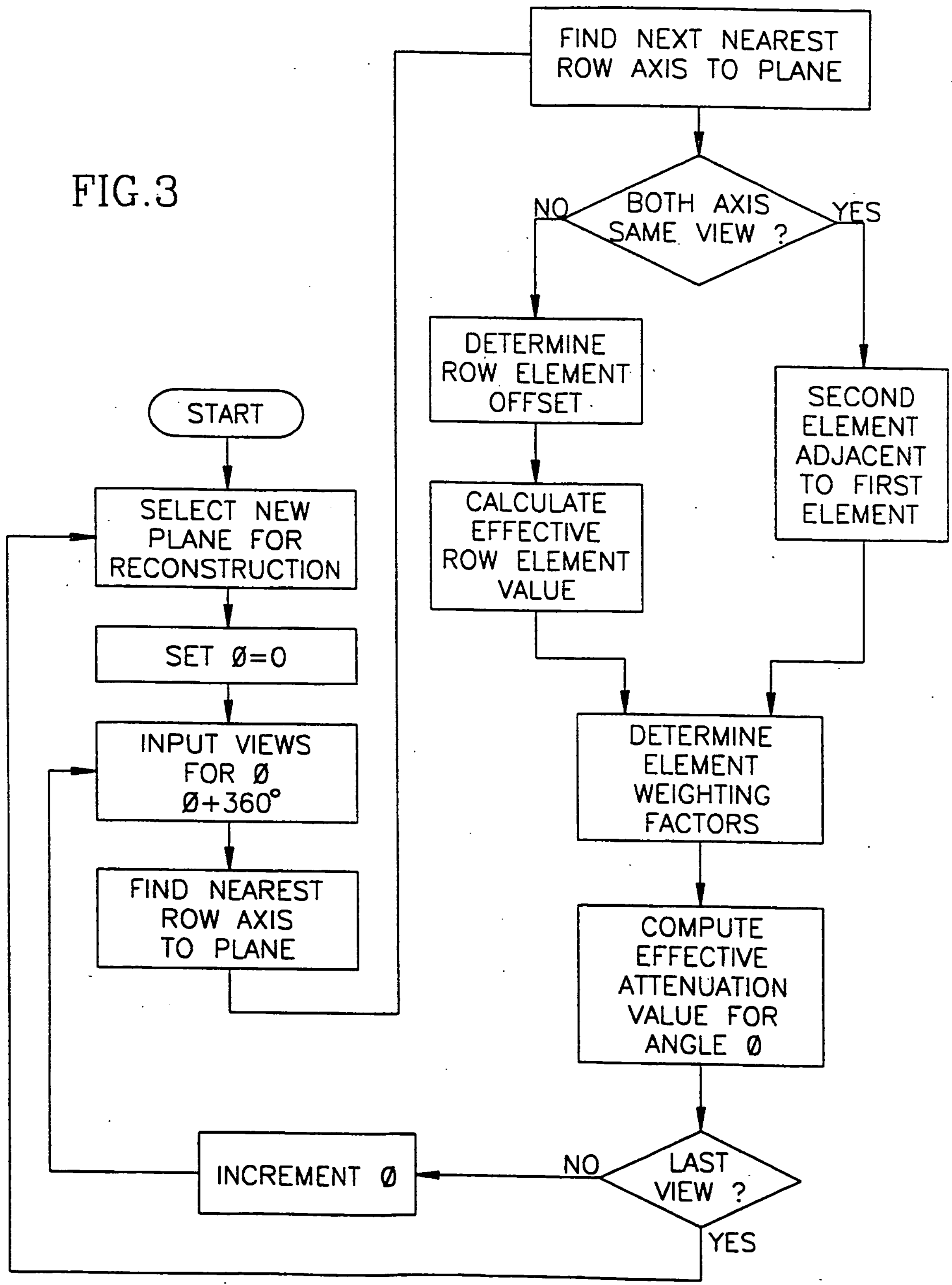

30
Y'
VIEW 1'
X
27
30
VIEW 2'
D1M
27
29
D2,K+3
D1,K+3
29
D2M
P
23
55
56
D2K
D1K
Z'
34
Θ
D11
52a
54a
52b
54b
D21
Z
ΔZ'

FIG.2B

FIG.3


START
SELECT NEW PLANE FOR RECONSTRUCTION
SET Ø=0
INPUT VIEWS FOR Ø Ø+360°
FIND NEAREST ROW AXIS TO PLANE
FIND NEXT NEAREST ROW AXIS TO PLANE
BOTH AXIS SAME VIEW ?
NO
YES
DETERMINE ROW ELEMENT OFFSET
CALCULATE EFFECTIVE ROW ELEMENT VALUE
SECOND ELEMENT ADJACENT TO FIRST ELEMENT
DETERMINE ELEMENT WEIGHTING FACTORS
COMPUTE EFFECTIVE ATTENUATION VALUE FOR ANGLE Ø
LAST VIEW ?
NO
YES
INCREMENT Ø

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 97/00069

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61B6/03 G06T11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61B G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 515 409 A (HSIEH) 7 May 1996 see the whole document ---	1,2,15, 17
A	OGAWA ET AL.: "Improvement of image quality by tilted fan beam data acquisition in a helical scan x-ray CT" 1996 IEEE NUCLEAR SCIENCE SYMPOSIUM CONFERENCE RECORD, vol. 2, 2 - 9 November 1996, NEW YORK, US, pages 1448-1452, XP002047533 see page 1448, left-hand column, line 1 - page 1449, right-hand column, line 16 see figures 1-7 ---	1,10,14, 15,17
A	US 5 513 236 A (HUI) 30 April 1996 see column 2, line 47 - column 5, line 53 see figures ---	1,13
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
19 November 1997	09/12/1997

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Chen, A

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 97/00069

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 291 402 A (PFOH) 1 March 1994 see column 9, line 5 - column 10, line 40 see figures 3-6D -----	1-3,9, 14,16,17

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int. .tional Application No
PCT/IL 97/00069

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5515409 A	07-05-96	DE 19544349 A	27-06-96
		JP 8294482 A	12-11-96
US 5513236 A	30-04-96	DE 19547277 A	25-07-96
		JP 8263638 A	11-10-96
US 5291402 A	01-03-94	US 5430783 A	04-07-95
		WO 9512353 A	11-05-95
		US 5469486 A	21-11-95
		US 5377250 A	27-12-94

PA' .IT COOPERATION TREAT\

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

United States Patent and Trademark Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing: 27 August 1998 (27.08.98)	
International application No.: PCT/IL98/00074	Applicant's or agent's file reference: 043/00217
International filing date: 12 February 1998 (12.02.98)	Priority date: 20 February 1997 (20.02.97)
Applicant: DAFNI, Ehud et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

12 July 1998 (12.07.98)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer: J. Zahra Telephone No.: (41-22) 338.83.38

PA :T COOPERATION TREAT\

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

FENSTER, Paul
Fenster & Company
P.O. Box 2741
49127 Petach Tikva
ISRAËL

Date of mailing (day/month/year) 08 July 1999 (08.07.99)	
Applicant's or agent's file reference 043/00217	**IMPORTANT NOTIFICATION**
International application No. PCT/IL98/00074	International filing date (day/month/year) 12 February 1998 (12.02.98)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
ELSCINT LTD. P.O. Box 550 31004 Haifa Israel	IL	IL
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [X] the name [X] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
PICKER MEDICAL SYSTEMS, LTD. P.O. Bc:x 325 31004 Haifa Israel	IL	IL
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Athina Nickitas-Etienne Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

PCT

To:
FENSTER & Company
PATENT ATTORNEYS
Attn. FENSTER, P.
P.O. BOX 2741
49127 Petach Tikva
ISRAEL

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 15/06/1998
Applicant's or agent's file reference 043/00217	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/IL 98/00074	International filing date *(day/month/year)* 12/02/1998
Applicant ELSCINT LTD. et al.	

1. [X] The applicant is hereby notified that the International Search Report has been established and is transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

   When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

   Where? Directly to the International Bureau of WIPO
   34, chemin des Colombettes
   1211 Geneva 20, Switzerland
   Fascimile No.: (41-22) 740.14.35

   For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   [ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicants's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   [ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

   Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

   Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Rosanna D'Errico Guarino

Form PCT/ISA/220 (January 1994)

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule", and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international pbulication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether

(i) the claim is unchanged;

(ii) the claim is cancelled;

(iii) the claim is new;

(iv) the claim replaces one or more claims as filed;

(v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]:
"Claims 1 to 29, 31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."

2. [Where originally there were 15 claims and after amendment of all claims there are 11]:
"Claims 1 to 15 replaced by amended claims 1 to 11."

3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]:
"Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
"Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."

4. [Where various kinds of amendments are made]:
"Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international appplication is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequence if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the same time of filing the amendments with the International Bureau, also file a copy of such amendments with the International Preliminary Examining Authority (see Rule 62.2(a), first sentence).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, where upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see Volume II of the PCT Applicant's Guide.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
043/00217		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/IL 98/ 00074	12/02/1998	20/02/1997
Applicant		
ELSCINT LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. [ ] **Certain claims were found unsearchable** (see Box I).

2. [ ] **Unity of invention is lacking** (see Box II).

3. [ ] The international application contains disclosure of a **nucleotide and/or amino acid sequence listing** and the international search was carried out on the basis of the sequence listing
   - [ ] filed with the international application.
   - [ ] furnished by the applicant separately from the international application,
     - [ ] but not accompanied by a statement to the effect that it did not include matter going beyond the disclosure in the international application as filed.
   - [ ] Transcribed by this Authority

4. With regard to the **title**,
   - [X] the text is approved as submitted by the applicant
   - [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,
   - [X] the text is approved as submitted by the applicant
   - [ ] the text has been established. according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this International Search Report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is:

   Figure No. 4
   - [ ] as suggested by the applicant.
   - [ ] because the applicant failed to suggest a figure.
   - [X] because this figure better characterizes the invention.

   [ ] None of the figures.

Form PCT/ISA/210 (first sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/[illegible]8/00074

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61B6/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	FR 2 679 435 A (ELSCINT) 29 January 1993 see the whole document ---	1,7-12, 25-28
A	US 3 866 047 A (EMI) 11 February 1975 see column 2, line 31 - column 11, line 30 ---	2-6, 13-23, 25-28
A	EP 0 662 305 A (PICKER) 12 July 1995 see page 4, line 34 - page 8, line 55 ---	1,7-12, 25-28
A	US 5 291 402 A (GENERAL ELECTRIC) 1 March 1994 see column 7, line 15 - column 10, line 56 --- -/--	1,7-12, 25-28

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 June 1998	15/06/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lemercier, D

1

International Application No
PCT/[illegible]98/00074

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 412 562 A (KABUSHIKI KAISHA TOSHIBA) 2 May 1995 see column 9, line 34 - column 12, line 36 ---	1-28
A	US 5 546 439 A (GENERAL ELECTRIC) 13 August 1996 see column 2, line 55 - column 4, line 55 -----	1,7-12, 25-28

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/[illegible]8/00074

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
FR 2679435	A	29-01-1993	DE	4224249	A	28-01-1993
			JP	5184563	A	27-07-1993
			NL	9201325	A	16-02-1993
US 3866047	A	11-02-1975	US	3944833	A	16-03-1976
			CA	949233	A,B	11-06-1974
			DE	1941433	A	26-02-1970
			FR	2019365	A	03-07-1970
			GB	1283915	A	02-08-1972
			HK	19377	A	06-05-1977
			NL	6912896	A,B,	25-02-1970
			US	4399509	A	16-08-1983
			US	3867634	A	18-02-1975
			US	3778614	A	11-12-1973
			US	3919552	A	11-11-1975
			US	3924131	A	02-12-1975
			US	4639941	A	27-01-1987
EP 662305	A	12-07-1995	US	5485493	A	16-01-1996
			JP	7204195	A	08-08-1995
US 5291402	A	01-03-1994	US	5430783	A	04-07-1995
			WO	9512353	A	11-05-1995
			US	5469486	A	21-11-1995
			US	5377250	A	27-12-1994
US 5412562	A	02-05-1995	JP	2622064	B	18-06-1997
			JP	6078916	A	22-03-1994
US 5546439	A	13-08-1996	DE	19624293	A	07-05-1997
			JP	9182745	A	15-07-1997

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

FENSTER, P.
FENSTER & Company
PATENT ATTORNEYS
P.O. BOX 2741
49127 Petach Tikva
ISRAEL

RECEIVED
22 -06- 1999
FENSTER & Co.

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing (*day/month/year*)	15.06.99
Applicant's or agent's file reference 043/00217	**IMPORTANT NOTIFICATION**

International application No.	International filing date (*day/month/year*)	Priority date (*day/month/year*)
PCT/IL98/00074	12/02/1998	20/02/1997

Applicant
ELSCINT LTD. et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

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Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 043/00217	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/IL98/00074	International filing date *(day/month/year)* 12/02/1998	Priority date *(day/month/year)* 20/02/1997
International Patent Classification (IPC) or national classification and IPC A61B6/03		
Applicant ELSCINT LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☐ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
12/07/1998	15. 06. 99
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. (+49-89) 2399-0 Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Authorized officer Sonntag, A Telephone No. (+49-89) 2399 2549

I. Basis of the report

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

Description, pages:

1-16 as originally filed

Claims, No.:

1-54 as received on 17/05/1999 with letter of 13/05/1999

Drawings, sheets:

1/4-4/4 as originally filed

2. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application.

☒ claims Nos. 1-54.

because:

☒ the said international application, or the said claims Nos. 1-28 relate to the following subject matter which does not require an international preliminary examination (*specify*):

see separate sheet

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 1-54 are so unclear that no meaningful opinion could be formed (*specify*):

see separate sheet

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

see separate sheet

III. NON-ESTABLISHMENT OF OPINION WITH REGARD TO NOVELTY, INVENTIVE STEP AND INDUSTRIAL APPLICABILITY

1. The step of acquiring additional X-ray attenuation data is considered to be implicit in present claim 1. In particular, from the description (see for example page 1, lines 3 and 4; page 2, lines 7-15; page 3, line 1) and from dependent claims 3 and 4 it is clear that the claimed subject-matter deals with near-real-time CT imaging of physiological processes and interventional treatments. The step of scanning the patient with X-rays must therefore be part of the claimed method.

   X-ray investigations for diagnostic purposes are actually not treatment of the human body by surgery or therapy, and they correspond to a diagnostic method providing only intermediate results which on their own do not enable a decision to be made on the treatment necessary. However, every medical staff agrees to acknowledge X-ray investigations as dangerous for the patient, so that for example a doctor only orders such investigations in absolute necessity, i.e. when the profit to be expected is greater than the damage caused. X-radiation constitutes in fact an invasion of the living substance, and leads to permanent changes in the human body.

   Furthermore, the goal of the lawgiver must be considered in this context, and in particular his ethical motivation. The purpose of the limitation defined in Rule 67.1(iv) PCT (or in corresponding Article 52(4) EPC) was to exclude any inhibition in the practice of medicine by patent legislation.

   Consequently, claim 1 relate to a subject-matter on which it is considered that an international preliminary examination in not required under Article 34(4)a)i) and Rule 67.1iv).

2. The same objection applies to claims 2-12 which are dependent on claim 1, to claims 13-22 wherein the defined image updating utilizes the method of claims 1-12, to claims 24, 26, 27 and 28 which define periodically updating the image in a region of interest in which change are expected.

3. Independent claims 23 and 25 do not contain all the features essential to the definition of the invention since they do not define any feature which would permit the imaging of dynamic physiological processes and interventional procedures as announced on page 1, lines 3 and 4 and as it is clear from the description taken in a whole. They do therefore not meet the requirement following from Article 6 PCT taken in combination with Rule 6.3(b) PCT that any independent claim must contain all the technical features essential to the definition of the invention.

4. Although claims 1, 13, 23, 25 and 27 have been drafted as separate independent claims, they appear to relate effectively to the same subject-matter and to differ from each other only with regard to the definition of the subject-matter for which protection is sought and/or in respect of the terminology used for the features of that subject-matter and/or comprise all the features of another independent or of its dependent claim. The aforementioned claims therefore lack conciseness.

   Moreover, lack of clarity of the claims as a whole arises, since the plurality of independent claims makes it difficult, if not impossible, to determine the matter for which protection is sought, and places an undue burden on others seeking to establish the extent of the protection.

   Hence, independent claims 1, 13, 23, 25 and 27 do not meet the requirements of Article 6 PCT.

5. The comment about too many independent claims applies also for the apparatus claims. Claims 29, 41 and 51 have been drafted as separate independent claims.

   However they appear to relate effectively to the same subject-matter and to differ from each other only with regard to the definition of the subject-matter for which protection is sought and/or in respect of the terminology used for the features of that subject-matter or to comprise respectively all the feature of another independent claim. The attention of the applicant is for example drawn to page 7, lines 1 and 28 and to page 8, lines 1 and 9 from which it is clear that the subject-matter of some present independent claims corresponds to embodiment of the

invention and not to the invention itself and that said subject-matter could be formulated as dependent claims.

The aforementioned claims therefore lack conciseness. Moreover, lack of clarity of the claims as a whole arises, since the plurality of independent claims makes it difficult, if not impossible, to determine the matter for which protection is sought, and places an undue burden on others seeking to establish the extent of the protection.

Hence, claims 29, 41 and 51 do not meet the requirements of Article 6 PCT.

In view of the above objection it is not at present practicable to carry out a full examination of the application.

VII. CERTAIN DEFECTS

1. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

2. The description is not in conformity with the claims as required by Rule 5.1(a)(iii) PCT.

CLAIMS

1. A method for modifying a planar image slice in a CT scanner having a predetermined reconstruction angle, comprising:

reconstructing an image of the slice using initial X-ray attenuation data acquired along an initial scan path sector; and

modifying the image to provide a modified image of the slice, responsive to additional X-ray attenuation data acquired along an additional scan path sector in a vicinity of the axial position of the slice, the sector having an angular extent substantially less than the reconstruction angle.

2. A method according to claim 1, and comprising defining a region of interest within the image slice, wherein modifying the image comprises modifying only a portion of the image corresponding to the region of interest.

3. A method according to claim 2, wherein defining the region of interest comprises identifying an object of interest and altering the region of interest in response to movement of the object.

4. A method according to claim 3, wherein altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest in response to a change is the characteristic.

5. A method according to claim 4, wherein determining the characteristic of the X-ray attenuation data comprises finding a maximum value of the data within a data window corresponding to the region of interest.

6. A method according to claim 5, wherein finding the maximum value of the data comprises pre-processing the data and finding a maximum value of the pre-processed data.

7. A method according to any of the preceding claims, wherein the data acquired along the initial and additional scan path sectors comprises multi-slice data acquired along the sectors of the scan path.

8. A method according to any of the preceding claims, wherein data acquired along the sectors of the scan path comprises data acquired along sectors of a helical scan path.

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9. A method according to claim 7, wherein data acquired along the scan path sectors comprises data acquired along sectors of a generally circular scan path substantially within a plane at the axial position of the slice.

10. A method according to any of the preceding claims, wherein modifying the image responsive to the additional attenuation data comprises processing the additional attenuation data and the initial attenuation data to produce an image data matrix and adding the matrix to the image.

11. A method according to claim 10, wherein processing the attenuation data to produce the image data matrix comprises:

back-projecting attenuation values calculated from the additional data, to determine a first preliminary matrix;

back-projecting attenuation values calculated from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector, to determine a second preliminary matrix; and

subtracting the second preliminary matrix from the first preliminary matrix to produce the image data matrix.

12. A method according to claim 10, wherein processing the attenuation data to produce the image data matrix comprises:

calculating initial attenuation values from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector;

calculating additional attenuation values from the additional data;

subtracting the initial attenuation values from the additional attenuation values to determine difference values; and

back-projecting the difference data to produce the image data matrix.

13. A method for producing a CT image of a region of interest within the body of a subject, comprising:

reconstructing a CT image of a slice of the body;

defining the region of interest; and

updating the CT image only in the region of interest, wherein the image of the region of interest encompasses only a portion of the CT image of the slice.

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14. A method according to claim 13, and comprising superimposing the CT image of the region of interest on another CT image encompassing a substantially greater portion of the cross-sectional area.

15. A method according to claim 14 wherein the updated image of the region of interest is produced utilizing the method of any of claims 1-12.

16. A method according to any of claims 13-15 wherein the region of interest is determined based on an expectation of change in the CT image in the region of image.

17. A method according to any of claims 13-16, and including identifying an object of interest and wherein defining the region of interest comprises defining the region of interest in response to a determination of the position of the object of interest.

18. A method according to claim 17 and comprising altering the region of interest being reconstructed in response to movement of the object.

19. A method according to claim 18, wherein altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest being reconstructed in response to a change in the characteristic.

20. A method according to claim 19, wherein determining the characteristic of the X-ray attenuation data comprises finding an extremum value of the data within a data window corresponding to the region of interest.

21. A method according to claim 20, wherein finding the extremum value of the data comprises preprocessing the data and finding a maximum value of the pre-processed data.

22. A method according to any of claims 17-21 wherein the CT image is a multi-slice image and wherein the position of the slices are determined based on a determination of the position of the object with respect to the slices.

23. A method of determining an optimal position for multiple CT slices, comprising:
reconstructing the multiple slices based on a first set of data;
determining the position of an object in the slices;
then reconstructing the slices based on the determined position.

24. A method according to any of claims 17-23 wherein the object is a biopsy needle.

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25. An imaging method for the determination of the position of a biopsy needle comprising:

reconstructing a CT image from a plurality of views;

determining the position of the biopsy needle in the image; and

determining a region of interest based on the determined position of the biopsy needle.

26. An imaging method according to claim 25 and including periodically updating the image only in the region of interest.

27. An imaging method for imaging a region in a region of interest in which changes are expected comprising:

reconstructing a CT image from a plurality of views; and

periodically modifying the image only in the region of interest.

28. An imaging method according to any of claims 13-22, 26 or 27 wherein the image is periodically modified utilizing the method of any of claims 1-12.

29. A CT scanner having a predetermined reconstruction angle, comprising:

means for reconstructing an image of the slice using initial X-ray attenuation data acquired along an initial scan path sector; and

means for modifying the image to provide a modified image of the slice, responsive to additional X-ray attenuation data acquired along an additional scan path sector in a vicinity of the axial position of the slice, the sector having an angular extent substantially less than the reconstruction angle.

30. A scanner according to claim 29, and comprising means for defining a region of interest within the image slice, wherein the means for modifying the image comprises means for modifying only a portion of the image corresponding to the region of interest.

31. A scanner according to claim 30, wherein means for defining the region of interest comprises means for identifying an object of interest and altering the region of interest in response to movement of the object.

32. A scanner according to claim 31, wherein the means for altering the region of interest in response to movement of the object comprises means for determining a characteristic of the X-ray attenuation data indicative of the position of the object, and for shifting the region of interest in response to a change is the characteristic.

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33. A scanner according to claim 32, wherein the means for determining the characteristic of the X-ray attenuation data comprises means for finding a maximum value of the data within a data window corresponding to the region of interest.

34. A scanner according to claim 33, wherein the means for finding the maximum value of the data comprises means for pre-processing the data and for finding a maximum value of the pre-processed data.

35. A scanner according to any of claims 29-34, wherein the data acquired along the initial and additional scan path sectors comprises multi-slice data acquired along the sectors of the scan path.

36. A scanner according to any of claims 29-35, wherein data acquired along the sectors of the scan path comprises data acquired along sectors of a helical scan path.

37. A scanner according to claim 35, wherein data acquired along the scan path sectors comprises data acquired along sectors of a generally circular scan path substantially within a plane at the axial position of the slice.

38. A scanner according to any of claims 29-37, wherein said means for modifying the image responsive to the additional attenuation data comprises means for processing the additional attenuation data and the initial attenuation data to produce an image data matrix and adding the matrix to the image.

39. A scanner according to claim 38, wherein the means for processing the attenuation data to produce the image data matrix comprises:

means for back-projecting attenuation values calculated from the additional data, to determine a first preliminary matrix;

means for back-projecting attenuation values calculated from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector, to determine a second preliminary matrix; and

means for subtracting the second preliminary matrix from the first preliminary matrix to produce the image data matrix.

40. A scanner according to claim 29, wherein the means for processing the attenuation data to produce the image data matrix comprises:

means for calculating initial attenuation values from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector;

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means for calculating additional attenuation values from the additional data;

means for subtracting the initial attenuation values from the additional attenuation values to determine difference values; and

means for back-projecting the difference data to produce the image data matrix.

41. A scanner for producing a CT image of a region of interest within the body of a subject, comprising:

means for reconstructing a CT image of a slice of the body;

means for defining the region of interest; and

means for updating the CT image only in the region of interest, wherein the image of the region of interest encompasses only a portion of the CT image of the slice.

42. A scanner according to claim 41, and comprising means for superimposing the CT image of the region of interest on another CT image encompassing a substantially greater portion of the cross-sectional area.

43. A scanner according to claim 42 and including the apparatus of any of claims 29-40 for producing the updated image of the region of interest.

44. A scanner according to any of claims 41-43 including means for determining the region of interest based on an expectation of change in the CT image in the region of image.

45. A scanner according to any of claims 41-44, and including means for identifying an object of interest and for defining the region of interest in response to a determination of the position of the object of interest.

46. A scanner according to claim 45 and comprising means for altering the region of interest being reconstructed in response to movement of the object.

47. A scanner according to claim 46, wherein the means for altering the region of interest in response to movement of the object comprises means for determining a characteristic of the X-ray attenuation data indicative of the position of the object, and means for shifting the region of interest being reconstructed in response to a change in the characteristic.

48. A scanner according to claim 47, wherein the means for determining the characteristic of the X-ray attenuation data comprises means for finding an extremum value of the data within a data window corresponding to the region of interest.

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49. A scanner according to claim 48, wherein the means for finding the extremum value of the data comprises means for preprocessing the data and finding a maximum value of the preprocessed data.

50. A scanner according to any of claims 45-49 wherein the CT image is a multi-slice image and wherein the position of the slices are determined based on a determination of the position of the object with respect to the slices.

51. A CT scanner including means for determining an optimal position for multiple CT slices, comprising:

means for reconstructing the multiple slices based on a first set of data;

means for determining the position of an object in the slices; and

means for then reconstructing the slices based on the determined position.

52. A scanner according to claim 51 and including means for periodically updating the image only in the region of interest.

53. A CT scanner for imaging a region in a region of interest in which changes are expected comprising:

means for reconstructing a CT image from a plurality of views; and

means for periodically modifying the image only in the region of interest.

54. A scanner according to any of claims 41-50 or 53 wherein the image is periodically modified utilizing the method of any of claims 1-12.

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CLAIMS

1. A method for modifying a planar image slice in a CT scanner having a predetermined reconstruction angle, comprising:

reconstructing an image of the slice using initial X-ray attenuation data acquired along an initial scan path sector;

acquiring additional X-ray attenuation data along an additional scan path sector in a vicinity of the axial position of the slice, the sector having an angular extent substantially less than the reconstruction angle; and

modifying the image, to provide a modified image of the slice, responsive to the additional attenuation data.

2. A method according to claim 1, and comprising defining a region of interest within the image slice, wherein modifying the image comprises modifying only a portion of the image corresponding to the region of interest.

3. A method according to claim 2, wherein defining the region of interest comprises identifying an object of interest and altering the region of interest in response to movement of the object.

4. A method according to claim 3, wherein altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest in response to a change is the characteristic.

5. A method according to claim 4, wherein determining the characteristic of the X-ray attenuation data comprises finding a maximum value of the data within a data window corresponding to the region of interest.

6. A method according to claim 5, wherein finding the maximum value of the data comprises pre-processing the data and finding a maximum value of the pre-processed data.

7. A method according to any of the preceding claims, wherein acquiring the data along the initial and additional scan path sectors comprises acquiring multi-slice data along the sectors of the scan path.

8. A method according to any of the preceding claims, wherein acquiring data along the sectors of the scan path comprises acquiring the data along sectors of a helical scan path.

9. A method according to claim 7, wherein acquiring the data along the scan path sectors comprises acquiring the data along sectors of a generally circular scan path substantially within a plane at the axial position of the slice.

10. A method according to any of the preceding claims, wherein modifying the image responsive to the additional attenuation data comprises processing the additional attenuation data and the initial attenuation data to produce an image data matrix and adding the matrix to the image.

11. A method according to claim 10, wherein processing the attenuation data to produce the image data matrix comprises:

back-projecting attenuation values calculated from the additional data, to determine a first preliminary matrix;

back-projecting attenuation values calculated from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector, to determine a second preliminary matrix; and

subtracting the second preliminary matrix from the first preliminary matrix to produce the image data matrix.

12. A method according to claim 10, wherein processing the attenuation data to produce the image data matrix comprises:

calculating initial attenuation values from the initial data that were acquired in a portion of the initial scan path sector corresponding to the additional scan path sector;

calculating additional attenuation values from the additional data;

subtracting the initial attenuation values from the additional attenuation values to determine difference values; and

back-projecting the difference data to produce the image data matrix.

13. A method for producing a CT image of a region of interest within the body of a subject, comprising:

reconstructing a CT image of a slice of the body;

defining the region of interest; and

updating the CT image only in the region of interest, wherein the image of the region of interest encompasses only a portion of the CT image of the slice.

14. A method according to claim 13, and comprising superimposing the CT image of the region of interest on another CT image encompassing a substantially greater portion of the cross-sectional area.

15. A method according to claim 14 wherein the updated image of the region of interest is produced utilizing the method of any of claims 1-12.

16. A method according to any of claims 13-15 wherein the region of interest is determined based on an expectation of change in the CT image in the region of image.

17. A method according to any of claims 13-16, and including identifying an object of interest and wherein defining the region of interest comprises defining the region of interest in response to a determination of the position of the object of interest.

18. A method according to claim 17 and comprising altering the region of interest being reconstructed in response to movement of the object.

19. A method according to claim 18, wherein altering the region of interest in response to movement of the object comprises determining a characteristic of the X-ray attenuation data indicative of the position of the object, and shifting the region of interest being reconstructed in response to a change in the characteristic.

20. A method according to claim 19, wherein determining the characteristic of the X-ray attenuation data comprises finding an extremum value of the data within a data window corresponding to the region of interest.

21. A method according to claim 20, wherein finding the extremum value of the data comprises preprocessing the data and finding a maximum value of the pre-processed data.

22. A method according to any of claims 17-21 wherein the CT image is a multi-slice image and wherein the position of the slices are determined based on a determination of the position of the object with respect to the slices.

23. A method of determining an optimal position for multiple CT slices, comprising:
reconstructing the multiple slices based on a first set of data;
determining the position of an object in the slices;
then reconstructing the slices based on the determined position.

24. A method according to any of claims 17-23 wherein the object is a biopsy needle.

25. An imaging method for the determination of the position of a biopsy needle comprising:
reconstructing a CT image from a plurality of views;
determining the position of the biopsy needle in the image; and
determining a region of interest based on the determined position of the biopsy needle.

26. An imaging method according to claim 25 and including periodically updating the image only in the region of interest.

27. An imaging method for imaging a region in a region of interest in which changes are expected comprising:
reconstructing a CT image from a plurality of views; and
periodically modifying the image only in the region of interest.

28. An imaging method according to claim 26 or 27 wherein the image is periodically modified utilizing the method of any of claims 1-12.